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Research and Development
Service
Washington, D.C. 20591

Synthetic Vision Technology Demonstration

1

Volume 4 of 4
Appendices

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Synthetic Vision Program Office
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Final Report

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16. Abstract

This report contains the description and results of a Synthetic Vision technology demonstration program conducted jointly by the Federal Aviation Administration, the Department of Defense and industry. The relevant technologies including millimeter wave radar sensors, infrared sensors, head-up displays, and computer processing were developed and tested in static tower tests and in flight tests in which the weather conditions were carefully measured and documented. The purpose of the program was to evaluate and demonstrate the performance of the imaging sensors and of the complete imaging system during aircraft approaches and landings in low-visibility conditions.

The static tower test facility used was the Avionics Tower Test Facility,located at Wright Patterson AFB, in which candidate sensors were set up at approximately 260 feet overlooking a nearby runway. The runway scene imaged by the sensors was instrumented to carefully measure the characteristics of fog, rain and snow as those conditions occurred in 1991-1992. Sensor performance and phenomenology was then fully characterized to provide a basis for further sensor development and for selection of sensors with which to proceed to flight test.

The test aircraft used was a Gulfstream II configured with a comprehensive data collection system and instrumentation to permit measurement of fog and precipitation through which the aircraft was flown as well as system and pilot performance during those operations. Millimeter wave sensors and an infrared sensor were used to provide an electronic image of the runway on both head-up and head-down displays during approach,landing and takeoff. Test and demonstration flights were flown into 27 difference airports in a wide variety of rain, fog and snow conditions during the period of May through December, 1992.

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LIST OF ILLUSTRATIONS (Continued)

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APPENDIX A

SYNTHETIC VISION SYSTEM TECHNOLOGY DEMONSTRATION SYSTEM INTEGRATION, EVALUATION AND DEMONSTRATION PROGRAM PLAN

Volume I and II

SVSTD/SIED PROGRAM PLAN - VOLUME I

PROGRAM MANAGEMENT

Contract F04606-90-D-0001/0017

SOW SM-ALC/TIE 91-308

Synthetic Vision System Technology Demonstration Project

System Integration, Evaluation, Demonstration Task

Document No. D1-6010

Version 1.0 Dated February 10, 1992

APPROVED:

Malcolm Burgess; FAA	Rich Tucker, TRW

CONCURRENCY:

Honeywell	Raleigh Jet Enterprises
GEC Avionics	Midcoast Aviation
Georgia Tech Research Institute	Norton Company
JTD	Kodak

DISTRIBUTED FOR REVIEW AND COMMENT:

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1. INTRODUCTION

The FAA/Government's Synthetic Vision System Technology Demonstration Project (SVSTD) has issued TRW, Inc. a Contractual Engineering Task (CET) for a "System Integration, Evaluation, and Demonstration" (SIED). TRW is to integrate, install, and operate a functional prototype synthetic vision system on-board an executive class aircraft to evaluate and demonstrate its capabilities. A number of engineering studies and support tasks will also be performed. TRW Avionics and Surveillance Group's Military Electronics and Avionics Division (MEAD) in San Diego, California is the responsible organization for implementation of the CET.

1.1 Purpose Of Plan

This SVSTD/SIED Program Plan provides a management overview of the SIED CET. It is intended to provide sufficient detail that the objectives, technical approach, management, implementation schedule, and resource allocations can be understood and evaluated. The SVSTD/SIED Program Plan is a living document which will be updated throughout the CET period of performance.

1.2 Scope Of Plan

This plan describes the efforts that will be performed under the U.S.A.F. Logistic Command's Microelectronics Technology Support Program (MTSP) Contract F04606-90D-0001, CET SOW No. 90-308, titled "Advanced Technology Synthetic Vision System". The CET is abbreviated SIED throughout the remainder of this document. The Synthetic Vision Project Office at NASA/Langley Research Center is the SIED Technical Monitor.

This SVSTD/SIED Program Plan is an internal document to TRW; but is included as a supplement to the *Task Accomplishment Plan* (CDRL Sequence No. A001). It is also provided as an informational document to the TRW team members and major vendors. It neither replaces nor supersedes the authority of the contracting documents.

1.3 Applicable Documents

The formal CDRL documents for the SIED are shown in Figure 1-1 along with their relationship to the major activities. Appendix C provides the outline of each document. The Safety Plan and Flight Test Plan are to be released by March 16, 1992 and the Final Report in December of 1992.

1.4 Program Plan Updates

This plan reflects the status of the SIED as defined by official direction, contracts, procurements, and approved CDRL documents. It is updated as required to maintain congruence with the official documents. SVPO approval prior to each release will be obtained by the TRW Program Manager to assure that both parties agree on the depiction of the collected official documents. The current status is announced, and updates distributed in the monthly *Status Report* (CDRL Sequence No. X003). Copies are not distributed to SIED subcontractors and major vendors until approved by the SVPO. Inputs and comments from the subcontractors and major vendors are encouraged but are not required.

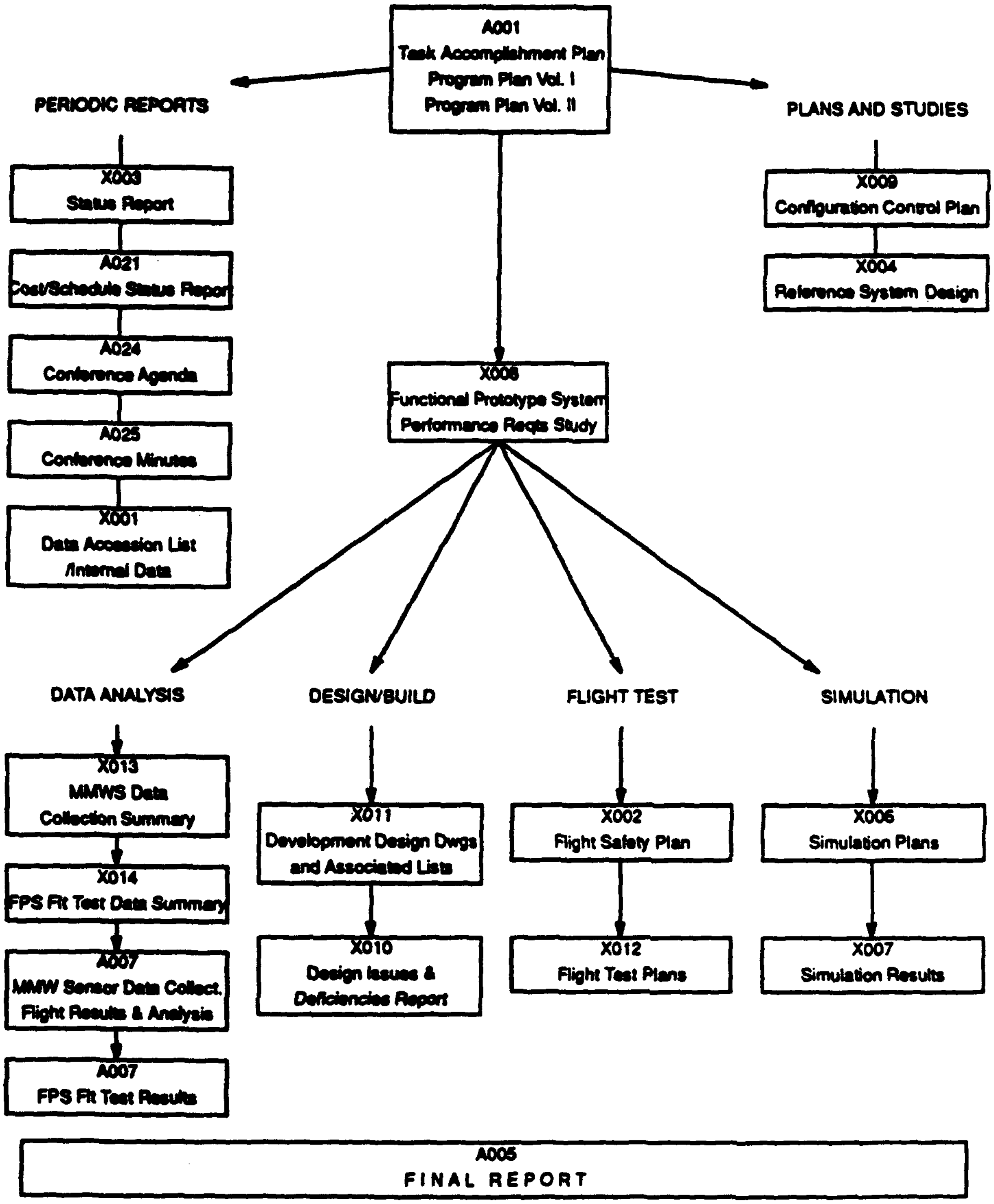

Figure 1-1. SIED Formal Documents

2. GOALS, OBJECTIVES AND METHODS

The SIED goal is to implement, demonstrate, and document the capabilities of current synthetic vision system technology to achieve safe aircraft landing, takeoff, and ground operations in very low visibility conditions. Specific objectives include:

A. Establish a technology benchmark through comprehensive documentation of actual system performance achieved in low visibility flight tests with a completely functional prototype Synthetic Vision System.

B. Provide the Secretariat and facilitate operations of the Joint Government/Industry Synthetic Vision Certification Issues Study Team.

C. Identify the microelectronic technology needed for production systems.

2.1 Technology Benchmark

This section summarizes the SIED experimental objectives and design as described in SVSTD/SIED Program Plan - Volume II (Experimental Design). The flight test operations required to implement the experimental design are described, and the analysis and approach to generating the final report is given.

2.1.1 Experimental Design Objectives

The experimental design objectives are:

A. Emperically measure the achieved performance of the integrated pilot / synthetic vision system during low visibility operations.

B. Assess the pilot's capabilities and workload when using the functional prototype synthetic vision system in low visibility operations.

C. Determine the operational characteristics of the imaging sensors used in the functional prototype synthetic vision system in terms of the airport environment and actual weather encountered.

   1. Physical phenomena of millimeter wavelength radar imaging of airport scenes at low grazing angles.

   2. Performance of the millimeter wavelength radar and its image processing under operational conditions.

   3. Performance of the forward looking infra-red sensor under operational conditions.

D. Determine, document, and correlate the actual weather conditions existing between the aircraft and the runway for all investigations.

E. Determine image quality in a manner that can be correlated to achieved perfomance and is transferable to generic synthetic vision systems.

2.1.2 Operational Scenarios

The following operational scenarios will be used for all flight testing:

A. A synthetic vision system is used to support manually flown precision approaches which may continue through the end of rollout in very low visibility conditions.

B. A synthetic vision system is used to support manually flown non-precision approaches which may continue through the end of rollout in very low visibility conditions.

C. A synthetic vision system is used to support manually flown enroute or off-airway approaches which may continue through the end of rollout in very low visibility conditions.

D. A synthetic vision system is used to support ground operations in very low visibilities.

These scenarios and the terminal operations tasks that must be accomplished with the synthetic vision system are shown in Figure 2-1 below:

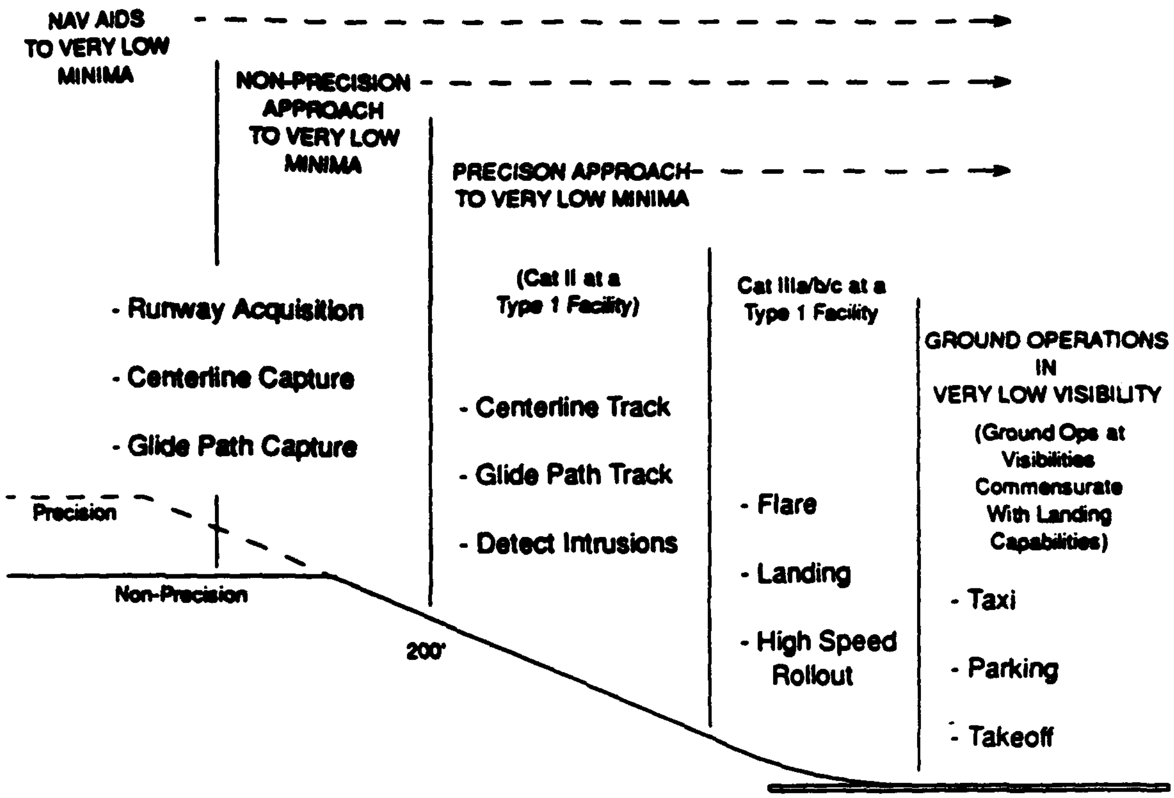

Figure 2-1. Terminal Operations Tasks By Operational Scenario

2.1.3 Operational Performance Assessment

Based on the piloting tasks identified in Figure 2-1, the following operational issues were established:

OPERATIONAL PERFORMANCE ISSUES			
Pilot Task	Scenario		
	Precision	Non-Precision	No Approach Aids
Airport Detection and Confirmation	No	Yes	Yes
Runway Detection and Confirmation	Yes	Yes	Yes
Runway Centerline Capture	No	Yes	Yes
Runway Centerline Track	Yes	Yes	Yes
Glide Path Capture	No	Yes	Yes
Glide Path Track	Yes	Yes	Yes
Flare and Touchdown Maneuver	Yes	Yes	Yes
Lateral Landing Maneuver	Yes	Yes	Yes
High Speed Rollout	Yes	Yes	Yes
Ground Operations	Yes	Yes	Yes
Takeoff Maneuver	Yes	Yes	Yes

Figure 2-2. Operational Performance Issues

For each of these issues the conditions of test, criterion for evaluation, analysis requirements, and data elements/sources were identified.

2.1.4 Flight Experiments

A series of experiments in measuring sensor performance and the resulting image quality have been established. The results of this effort provide basic phenomenology data, functional prototype sensor performance, and may allow the operational performance data to be extrapolated to future systems. Figure 2-3 shows the experiments to be performed:

FLIGHT EXPERIMENTS	
OBJECTIVE	**EXPERIMENT**
MMW Radar Phenomenology	Absolute Radar Cross Section (RCS) of Calibration Points Reflectivity of Runway and Surrounding Surfaces Path Attenuation of Different Weather Conditions Volumetric Backscatter of Different Weather Conditions
MMW Radar Performance	Runway Contrast To Surroundings Sharpness of Runway Edges Variability of Signals from Runway and Surroundings
FLIR Performance	Runway Contrast To Surroundings Sharpness of Runway Edges Variability of Runway and Surroundings

Figure 2-3. Flight Experiments

2.1.5 Test Conditions and Priorities

The test conditions identified and their priority for both the Operational Assessment and the Experiments are summarized in Figure 2-2 and are detaled in Section 7 of the SVSTD/SIED Program Plan - Volume II.

TEST CONDITIONS AND THEIR PRIORITIES	
CONDITION	**PRIORITY**
Visibility (Touchdown Zone RVR)	I-A
Weather Conditions	I-B
Sensor Used For Approach	I-C
Airport/Surrounding Surfaces	I-D
Calibration Reflectors Deployed	I-E
Runway Incursion / Obstacle Detection	II-A
Glide Path Intercept Altitude	II-B
Zero/Zero Demonstration	II-C
ILS Guidance Cutout	II-D
Approach Offset Angle	II-E
Display Used	III-A
Day/Night	III-B
Crosswinds	III-C
Flare Guidance Cue	III-D

Figure 2-4. Test Conditions And Their Priorities

2.1.6 Flight Operations Requirements

The flight operations part of the SIED involves turning the experimental design into the detailed test plan and matrix, conduction of flight operations to obtain the needed data, data reduction,

and analysis.

2.1.6.1 Suitability Flights:

A series of suitability flights will be used to assure that the imaging sensors and the integrated functional prototype synthetic vision system are functioning well enough to begin operational testing. Objectives of the suitability flight include:

A. Prove flight worthiness of the system.

B. Subjective determination of the viability of the MMW and FLIR sensors.

C. Check out HUD symbology and integration with the functional prototype SVS.

D. Check out HUD flight director for capture, track, and flare guidance adequacy.

E. Check out weather sensors.

F. Perform the MMW Radar calibration runs using the "Corner Reflectors" in clear weather.

The goal is to complete the suitability flying in approximatley 20 hours of flight time. To reduce cost and flight time, this portion of the program will be flown by a single pilot.

2.1.6.2 Baseline Establishment Flights:

This block of flight time establishes the operating baseline of the aircraft. Its objectives include:

A. Gain initial experience with the functional prototype SVS at local airports in weather with a ceiling of at least 200 feet and ¾ mile visibility for precision approaches and at least MDA and visibility greater than one statute mile for non-precision approaches.

   1. ILS approaches manually flown to Category IIIa decision height (50').
   2. Localizer approaches manually flown to Category I decision height (200') and then to Category IIIa decision height (50').
   3. Straight-in VOR approaches manually flown to Category I decision height (200').
   4. Establish ground operations capabilities.

B. Refine the operating and safety procedures.

C. Refine the data taking and crew coordination procedures.

D. Develop standardized interpretations of radar images (if necessary).

This baseline series of tasks is expected to be complete in 25 hours of flight time.

2.1.6.3 Phase A Testing:

Phase A flight testing is the period in which the bulk of the operational assessment and experiment data taking is performed. The major elements include:

A. Expand approved flight envelope to descend below published minima, including obtaining the necessary waivers.

B. Initiate testing with all three evaluation pilots. Operations involving pilot performance measurements have been designed with a nominal evaluation having all three pilots, with each pilot doing three repetitions. Assuming that their subjective ratings (Cooper-Harper) have a standard deviation of 1, a number shown to be probable in this type of test[1], the confidence level should approach 90%. The attained confidence level will vary with the actual standard deviation of the test ratings. The number of approaches per pilot may be

1. Dukes, Theodor A., *Guidelines for Designing Flying Qualities Experiments*. NADC-85130-69 June 1985.

dynamically adjusted to assure that the resources available are properly utilized.

C. Accomplish the test matrix in accordance with the established priorities.

Phase A is expected to require 175 hours of flight time, with the following allocations:

- 125 hours planned for actual approaches and their required set-ups.
- 50 hours of ferry time.
- The average sortie having 8 approaches (2 hours) and 0.8 hours of ferry.

2.1.7 Phase B Demonstrations

Phase B is a series of flight demonstrations given to representatives of government and industry. The content of the demonstration is designed to enhance understanding of the data reported from the Phase A flying.

2.1.8 Analysis/Final Report

The subjective analysis will be validated by extensive analytical data collected in real time. This will include:

A. Actual weather data, including total water content and water droplet size distributions.

B. Aircraft system data including navigation sensors, inertial measurement unit, air data computer, radar altimeter, weight-on-wheels, and event markers.

C. Video recordings of sensor, combined sensor/symbology displays, and pilot's out-the-window view. Figure 2-3 shows the video capability.

D. Recordings of raw sensor performance (generally proprietary to sensor manufacturer).

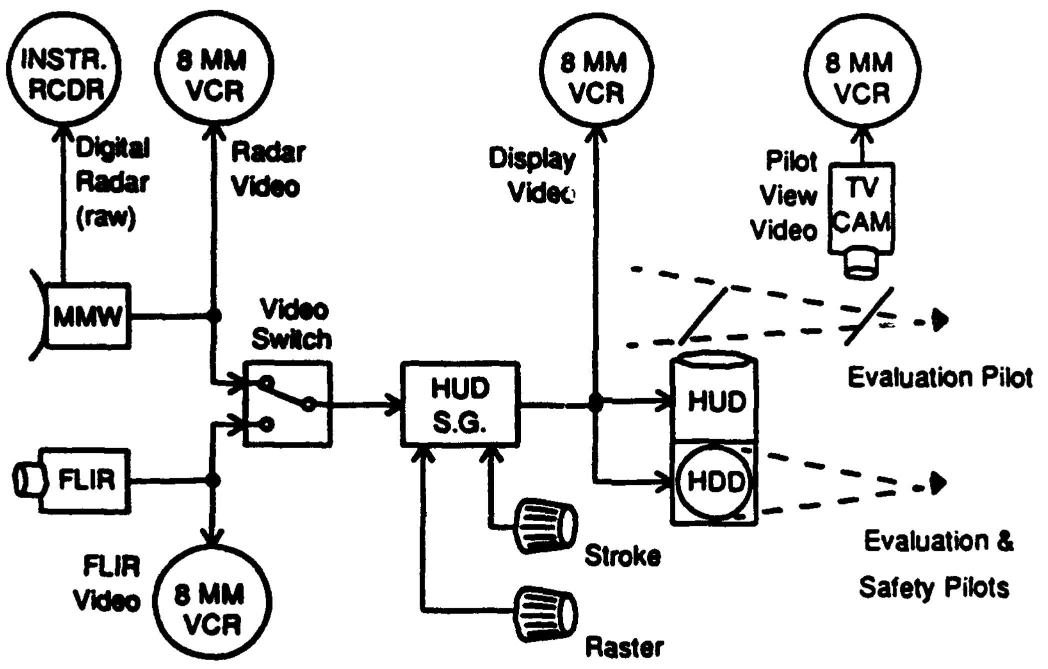

Figure 2-5. Imaging Sensor Recording Capability

2.2 Secretariat

TRW will provide leadership and resources in promoting the efforts of the Joint Government/Industry Synthetic Vision Certification Issues Study Team.

2.3 Micro-Electronic Technology

TRW will conduct two studies to support the identification of micro-electronic technology required for production systems.

- A *Reference System* study designed to identify design requirements a production synthetic vision system would have to meet.
- An assessment of the technology used in the Functional Prototype Synthetic Vision System and where advanced micro-electronic technology would make significant improvements in capability or production cost.

3. TECHNICAL APPROACH

The SIED will be implemented along a number of parallel paths, all culminating at the final report.

3.1 System Design

The system design effort can be broken down into three major areas:

3.1.1 System Analysis and Studies

These define the program requirements and are essential in providing guidance to the other tasks.

— Experiment and Scenario Definition and Test Methodology

— Flight Test Matrix

— Functional Prototype SVS Performance Requirements

— Sensor and System Data Analysis

— Required Data Elements and Data Acquisition Element Sources

— Simulation and Support Requirements

— Safety Plan

3.1.2 Simulation Studies

The primary role of simulation in the SIED is to reduce risk to the Functional Prototype Synthetic Vision System design and implementation. It also may be used to resolve important operational scenarios or experiments which cannot be reasonably performed in the aircraft. To provide for simulation results to be available to the design and early implementation phases, it is initiated using preliminary study results. Initial tuning of integration and symbology software will also be performed here. The curtailment of the traditionally extensive simulation role in avionics development is due primarily to the lack of a creditable simulation of MMW radar and the signal processing that makes it's conformal image.

3.1.3 Functional Prototype Definition, Implementation, and Integration

The definition and acquisition or development of the sub-systems which make up the Functional Prototype SVS include:

— Provisioning for two MMW sensors

— Head up and head down displays

— Forward looking infra-red sensor

— Cockpit controls

— Interface Unit

— Test and observer stations

— Implementation of safety plan requirements

— Data acquisition system

This task also involves the generation of detailed requirements and specifications, integration and test plans, and configuration management systems required to successfully integrate a complex system. A ground based "Hot Bench" fixture is used to integrate the system and perform the initial checkouts as a means to both reduce aircraft lease time and provide a known operating system to the aircraft integration task.

3.2 Aircraft Preparation

The aircraft provisioning for the functional prototype system will continue in parallel with its design

and build. This task includes the selection and acquisition of an Executive Class airplane and its preparation for use with the FPSVS.

3.2.1 Engineering

New subsystems will have to be installed on the aircraft. The engineering required includes:

— Design of a radome and forward bulkhead mounting system that supports interchangeable Lear and Honeywell MMW radars, a forward looking infra-red sensor, the weather radar, and glideslope antenna.

— A mounting pylon and aircraft hard mount point to support weather sensors.

— A head up display subsystem capable of displaying the FPSVS sensor images with flight symbology to the test pilot.

— Unique head down display capabilities to display the FPSVS sensor images with flight symbology to both test and safety pilots.

— Cockpit controls for the FPSVS.

— A cockpit window mounted TV camera.

— Cabin modifications required to support the FPSVS equipment.

— Wiring installations to electrically connect the FPSVS equipment, supporting sensors, data acquistion and recording, work stations, and the standard aircraft avionics.

— Additional power sources and protection for the FPSVS equipment and ancillary subsystems.

— Analysis and flight test required to assure that the installations are flight-worthy.

3.2.2 Aircraft Modification

This effort includes the fabrication and/or installation of the FPSVS and the items listed above. Also included is the de-modification of the aircraft and restoration of its capability to operate under Part 91/135 at the end of the SIED.

3.3 Flight Operations

3.3.1 Flight Planning

This path will first establish the flight planning and management parameters such as site selection, scheduling and TDY deployment, weather forecasting and management, experimental flight approval and restrictions, flight procedures, mission rules, and data handling procedures.

3.3.2 Suitability Flights

Suitability flights are designed to collect basic performance data on the two MMW Sensors to assure their operating capabilities are acceptable for integration into the functional prototype SVS.

3.3.3 Phase A Flights

Phase A flying tests the integrated FPSVS to determine its capabilities and limitations as well as its usefulness in operational scenarios. This includes conduct of identified experiments to explore specific areas of interest.

Initial pilot evaluation and confidence are gained by using the FPSVS with the test pilot in simulated IMC conditions. Then the majority of the flying involves operations in actual weather using the FPSVS as the primary approach aid. In all cases the safety pilot will be monitoring the approach using conventional nav- and ground aids such as ILS and PAR. Operations in very low visibility are a goal of this phase.

GTRI, acting as an independent laboratory, will provide independent analysis of the internal sensor performance for special test conditions and on a "as needed" basis to answer specific

performance questions. They will deliver the resulting data directly to the SVPO.

TRW will provide routine analysis of the non-proprietary FPSVS output as well as all the FLIR and out-the-window imaging sensors, weather sensors, avionics, and aircraft systems to answer the operational and experimental issues.

3.3.4 Phase B Flights

The capabilities of the FPSVS and its usefulness will be demonstrated to government and industry representatives. Data recording will continue on all demonstration flights. Analysis of the data may be performed by TRW if the flight meets continuing criteria for performance analysis.

3.4 Technical Support

3.4.1 Reference System Design

In order to understand the capabilities and limitations of the Functional Prototype SVS, a hypothetical paper design will be developed for a series of four Reference Systems which are estimated to be satisfactory for regulatory certification. The four designs support the following operational requirements:

- — SVS enhanced operations to lower minima with precision approach references.
- — SVS enhanced operations to lower minima with non-precision approach references.
- — Land in very low visibility without ground-based approach aids.
- — SVS enhanced ground operations including rollout, takeoff, and taxi.

3.4.2 Expert Technical Assistance and Technical Exchange Support

Provides expert technical support to the FAA/USAF project team addressing challenging synthetic vision issues and to the joint industry/government Synthetic Vision Certification Issues Study Team.

3.4.3 Certification Issues Study Team

The secretariat function for the joint industry/government Synthetic Vision Certification Issues Study Team (CIST) will be performed as part of this effort. This group is investigating the issues involved in the eventual commercial certification of synthetic vision technologies.

Although the CIST secretariat is part of the SIED scope, it is intended that the FPSVS integration, evaluation, and demonstration progress independently from the CIST efforts. The CIST will be kept appraised of the FPSVS progress and results.

3.5 Final Report

Considering the wide scope of the SIED, two final reports will be prepared. This first will cover the system integration, evaluation, and test for which the CET is named. A second report will cover the results of the engineering studies and the contributions of the Joint Government/Industry Synthetic Vision Certification Issues Study Team.

3.5.1 SIED Final Report

The SIED Final Report will contain the summary and results of all aspects of the system integration, evaluation, and demonstration of the functional prototype synthetic vision system. It will provide analytical documentation of the SIED that is intended to both validate the reported results and to form the basis for further government or industry study. Test data, conclusions, and recommendations are included along with the FPSVS design documents.

3.5.2 Synthetic Vision Studies Final Report

The Synthetic Vision Studies Report will contain the summary and results of all aspects of the Synthetic Vision studies performed under the SIED CET as well as the results of the Synthetic Vision Certification Issues Study Team and its committees.

4. SIED ORGANIZATION

The prime and sub-contractors and the major vendors are listed below with their respective SIED point of contact:

SIED CONTRACTORS AND KEY VENDORS		
Organization	**Contact**	**Telephone**
TRW/MEAD	Rich Tucker (SIED Program Mngr.)	(619) 592-3690
Raleigh Jet Enterprises	Joseph McGuire	(818) 902-3799
GEC Avionics	Trevor Bushell	(213) 305-8376
Eastman Kodak Company	Raymond Rehberg	(716) 253-2261
Georgia Tech Research Institute	Walter Horne	(404) 528-7874
Norton	Bob Algera	(216) 296-9948
JTD, Inc	Lawrence Jahnsen	(818) 794-2856
Mid-Coast Aviation	Joe Caesar	(618) 337-2100
Lear Astronics	Dutch Neilson	(213) 452-6099
Honeywell	Lavell Jordan	(612) 887-4050
Hoh Aeronautics	Roger Hoh	(213) 325-7255
Stuart W. Law Co.	Stuart Law	(713) 337-1935
Paul Mengers	Paul Mengers	(916) 265-2327
Robert Hayes	Robert Hayes	(404) 422-3646

Figure 4-1. SIED Contractors And Key Vendors

The responsibilities of these organizations are detailed in the WBS Task Descriptions contained in Appendix A to this document.

5. MANAGEMENT APPROACH

TRW is responsible for the management of all aspects of the SIED task and has established it as a TRW Program at the Military Electronics and Avionics Division (MEAD). Key elements of TRW's management approach include:

A. The SIED Program Office as the management focal point.

B. Dedication of a full time TRW Program Manager with direct access to Divisional Vice President levels as required. Mr. Rich Tucker is the SVSTD/SIED Program Manager.

C. Development and maintenance of a Work Breakdown Structure (WBS) which defines the tasks and schedules that all vendors, subcontractors, and internal personnel are to accomplish and their associated resource allocations.

D. Incorporation of all pertinent milestones into a single collection of schedules capable of determining program progress. Analysis, development, and maintenance of task dependency networks showing critical and near-critical paths across all vendors, subcontractors, and internal organizations.

E. Development of a resource allocation plan and establishment of a tracking mechanism with monthly resolution and timeliness to assure project resources are properly rationed to permit achievement of goals and objectives on schedule and within available resources.

F. Development and maintenance of Interface Control Documents for all hardware and/or software which is required by multiple organizational entities.

G. Judicious use of both "Firm Fixed Price" and "Time and Material" contracting to optimize flexibility and cost across the vendors and subcontractors. Management of each subcontractor's effort through a written Statement of Work (SOW) or Task Order implemented under a "Terms and Conditions Contract Authorization".

H. Establishment of an "Open Program" environment where both the major vendors and subcontractors are made aware of not only their portion, but also how that portion will integrate and be used with the overall system. Inputs, suggestions, and criticisms from all participants are encouraged both individually to the TRW Program Management Office and through informal Technical Interchange Meetings.

I. Communication via Technical Interchange Meetings and telephone with the SVPO will ensure that project work is maintaining schedule performance, that problems and concerns are being discussed, and that proper actions are being taken.

J. Planned reviews will assure that program requirements are being met and that the SIED operating as a single entity in the integration process. These include the formal Preliminary and Critical Design Reviews and Flight Readiness Reviews prior to each major flight phase.

6. WORK BREAKDOWN STRUCTURE

The following Work Breakdown Structure (WBS) provides an overview of the SIED that is detailed in Appendix A.

WORK BREAKDOWN STRUCTURE	
LEVEL	TITLE
A.	SIED Management
A.1	Program Management
A.1.1	TRW Program Office
A.1.2	Cost and Schedule Reporting
A.1.3	Status Report/Program Plan
A.1.4	Risk Management
A.2	Travel and ODC
A.3	Configuration Management
A.4	Subcontracts Management
A.5	Program Reviews
A.5.1	Technical Interchange Meetings
A.5.2	Formal Reviews
A.5.3	Flight Readiness Reviews
A.6	Data Items
B.	System Analysis and Studies
B.1	Operational Scenarios and Experiments
B.1.1	Operational Issues and Criteria
B.1.2	Test Methodology
B.1.3	Flight Test Conditions
B.1.4	Flight Test Matrix
B.1.5	Data Analysis Requirements
B.1.6	Data Elements and Sources
B.1.7	Flight Test Resource Management
B.2	Data Acquisition and Reduction
B.3	Data Analysis/Documentation
B.4	Final Report
B.5	GTRI Subcontract
B.6	JTD Subcontract
B.7	Simulation Studies
B.7.1	Simulation Objectives Definition
B.7.2	Facility Selection
B.7.3	Facility Preparation
B.7.4	Simulation Operations
B.8	Simulation Subcontractor
B.8.1	Facility Preparation
B.8.2	Simulation Operations
B.9	Engineering Plans and Schedule Development
B.9.1	Flight Test Plan
B.9.2	Safety Plan
C.	Functional Prototype SVS System Design
C.1	Requirements, System Engineering, and Specifications

WORK BREAKDOWN STRUCTURE	
LEVEL	TITLE
C.1.1	System Definition
C.1.2	Head Up Display
C.1.2.1	Specification
C.1.2.2	Technical Selection
C.1.2.3	Technical Support
C.1.3	Head Down Display
C.1.3.1	Specification
C.1.3.2	Technical Selection
C.1.4	Data Acquisition System
C.1.4.1	Definition
C.1.5	Hot Bench
C.2	Hardware Design
C.2.1	Head Down Display
C.2.1.1	HDD Electrical Design
C.2.2	Data Acquisition System
C.2.3	Test Director Work Station
C.2.4	Test Engineer Work Station
C.2.5	Observers Work Station
C.2.6	FPSVS Interface Unit
C.2.7	Hot Bench
C.3	Software Design
C.3.1	Data Reduction System
C.3.2	Data Acquisition System
C.4	Mechanical Design
C.5	Implementation and Integration
C.5.1	Head Down Display
C.5.1.1	HDD Acquisition
C.5.1.2	HDD Integration
C.5.2	FLIR
C.5.2.1	FLIR Acquisition
C.5.3	MMW Sensor Racks
C.5.4	Test Director Work Station
C.5.5	Test Engineer Work Station
C.5.6	Observers Work Station
C.5.7	FPSVS Interface Unit
C.5.8	Data Acquisition and Reduction System
C.6	Hot Bench
C.6.1	Hot Bench Integration Test
C.6.2	Hot Bench System Test and Evaluation
C.7	Lear Astronics Subcontract
C.8	GEC Subcontract
C.9	Kodak Subcontract
C.10	Honeywell Support
D.	Aircraft Preparation
D.1	Specifications and Acquisition
D.1.1	Test Aircraft

WORK BREAKDOWN STRUCTURE	
LEVEL	TITLE
D.1.2	FLIR Sensor
D.2	Raleigh Jet Subcontract
D.3	Midcoast Aviation Subcontract
D.3.1	Aircraft (Group A) Wiring
D.3.2	Aircraft Power
D.3.3	Aircraft Mechanical Design
D.3.4	Equipment Installation Design
D.3.5	Aircraft Equipment Acquisition/Fabrication
D.3.6	Aircraft Modification Installation
D.3.7	Head Up Display
D.3.8	FLIR
D.3.9	Lear MMW Radar
D.3.10	Honeywell MMW Radar
D.3.11	Aircraft Demodifications
D.4	Aircraft Engineering and Modifications
D.4.1	Interface Control Documents
D.4.2	Weather Pylon and Attachment
D.4.3	Aircraft Demodifications
D.4.4	FLIR System
D.4.4.1	FLIR Window Support
D.4.4.2	FLIR Mounts and Trays
D.4.5	MMW Sensor Systems
D.4.5.1	MMW Radome Support
D.5	Norton Subcontract
E.	Flight Operations
E.1	Operational Planning
E.1.1	Aircraft Experimental Operations Certificate
E.1.2	Operational Test Procedures
E.2	Aircraft Installation, Integration, and Test
E.2.1	System Integration and Checkout
E.2.2	Weather Sensor Pylon
E.2.3	Modifications
E.2.4	Head Up Display
E.2.5	FLIR
E.2.6	Lear MMW Radar
E.2.7	Honeywell MMW Radar
E.2.8	FPSVS Equipment
E.3	Flight Test
E.3.1	Aircraft Sortie Planning
E.3.2	Aircraft and Crew
E.3.3	Shakedown Flights
E.3.4	Sensor Suitability Flights
E.3.5	Phase A Flights
E.3.6	Phase B Flights
F.	Technical Support
F.1	Reference System Design & Program Support (Law)

WORK BREAKDOWN STRUCTURE	
LEVEL	**TITLE**
F.2	Technical Exchange & Program Support (Hoh)
F.3	SVSTD/CIST Expert Technical Assistance (Hayes)
F.4	CIST/SVPO Imaging Evaluation Assistance (Mengers)
F.5	Boston Harbor Vessel Detection (Hayes)

7. MAJOR MILESTONES

The following is a list of the major program milestones:

PROGRAM MILESTONES	
Aircraft Selection	March 1991
Task Accomplishment Plan	April 1991
Head Up Display Selection	April 1991
Radome Specifications	May 1991
FPSVS Requirements Study	June 1991
Simulation Requirements	June 1991
Preliminary Design Review	July 1991
Critical Design Review	December 1991/January 1992
35 GHz Radome Available	February 1992
Flight Test Plan	March 1992
Flight Safety Plan	March 1992
94 GHz Radome Available	April 1992
Bench Integration and Test	February 1992
FAA Experimental Certificate	March 1992
Flight Readiness Review	April 1992
Suitability Flights Sensor #1	April 1992
Suitability Flights Sensor #2	TBD 1992
Phase A Flight Test	May 1992
Phase B Flight Test	August 1992
Aircraft De-modifications	November 1992
Final Report	December 1992

Figure 7-1. Program Milestones

8. SCHEDULE

Figure 8.1 is the SVSTD/SIED Master Program Schedule. It presents the expected task periods and completion dates of the WBS elements as well as showing estimated completion of work relative to the status date.

Figure 8.2 is a Task Dependency Network Chart showing the dependencies between WBS elements. Critical path tasks are shown in shadow boxes. Start/Finish dates and the number of working days allocated are shown for each task.

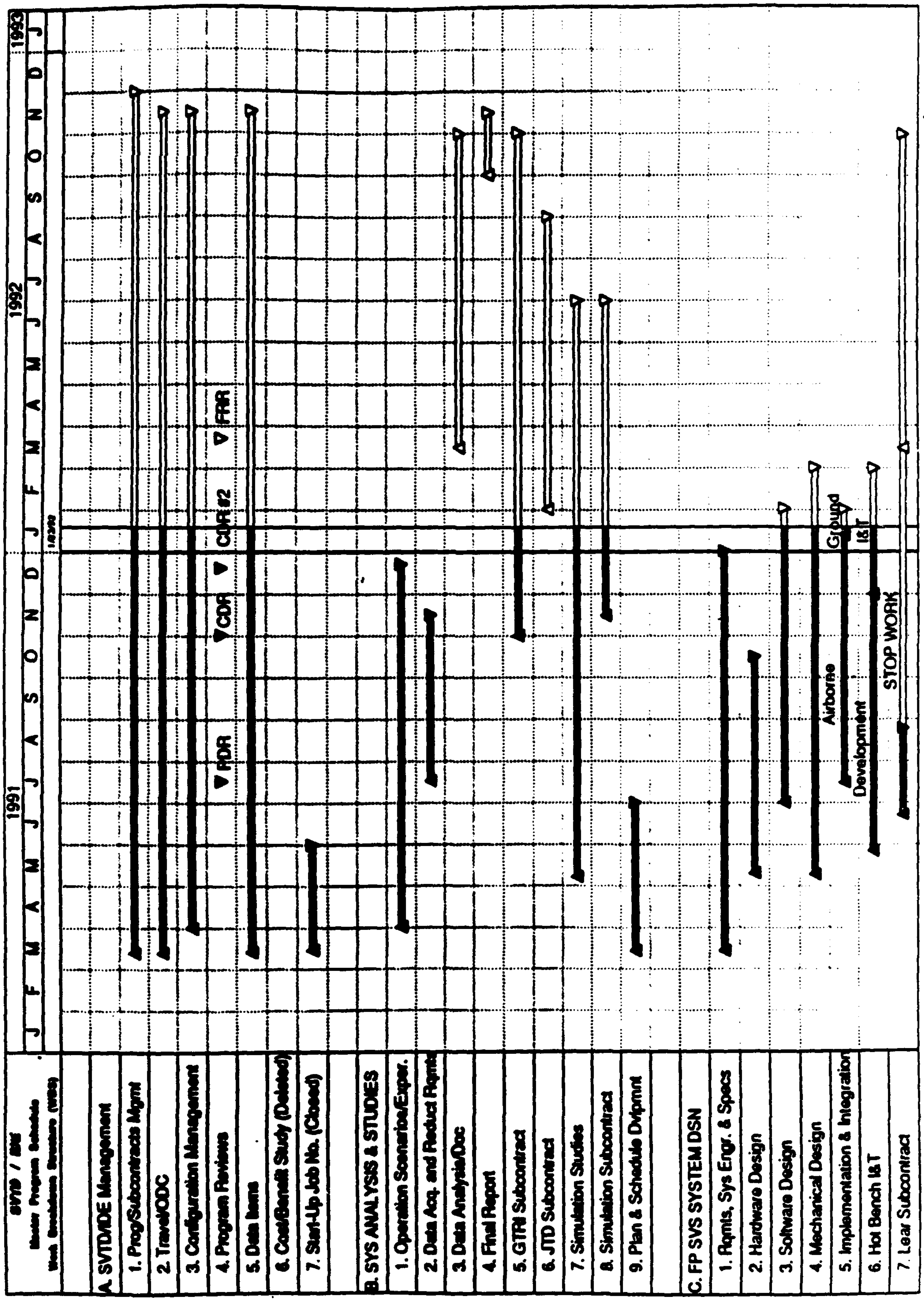

Figure 8-1. SVSTD/SIED Master Program Schedule

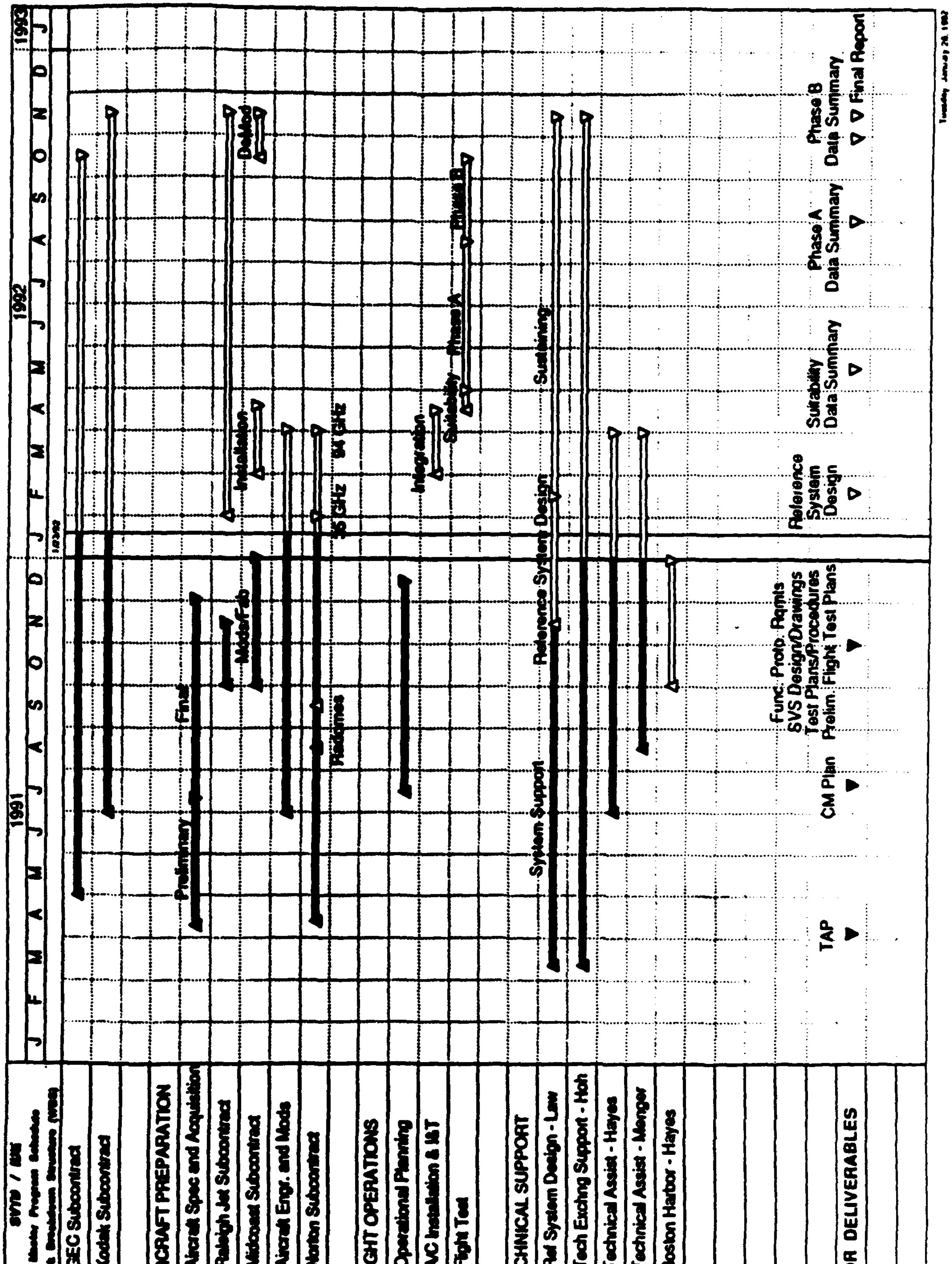

Figure 8-1. SVSTD/SIED Master Program Schedule

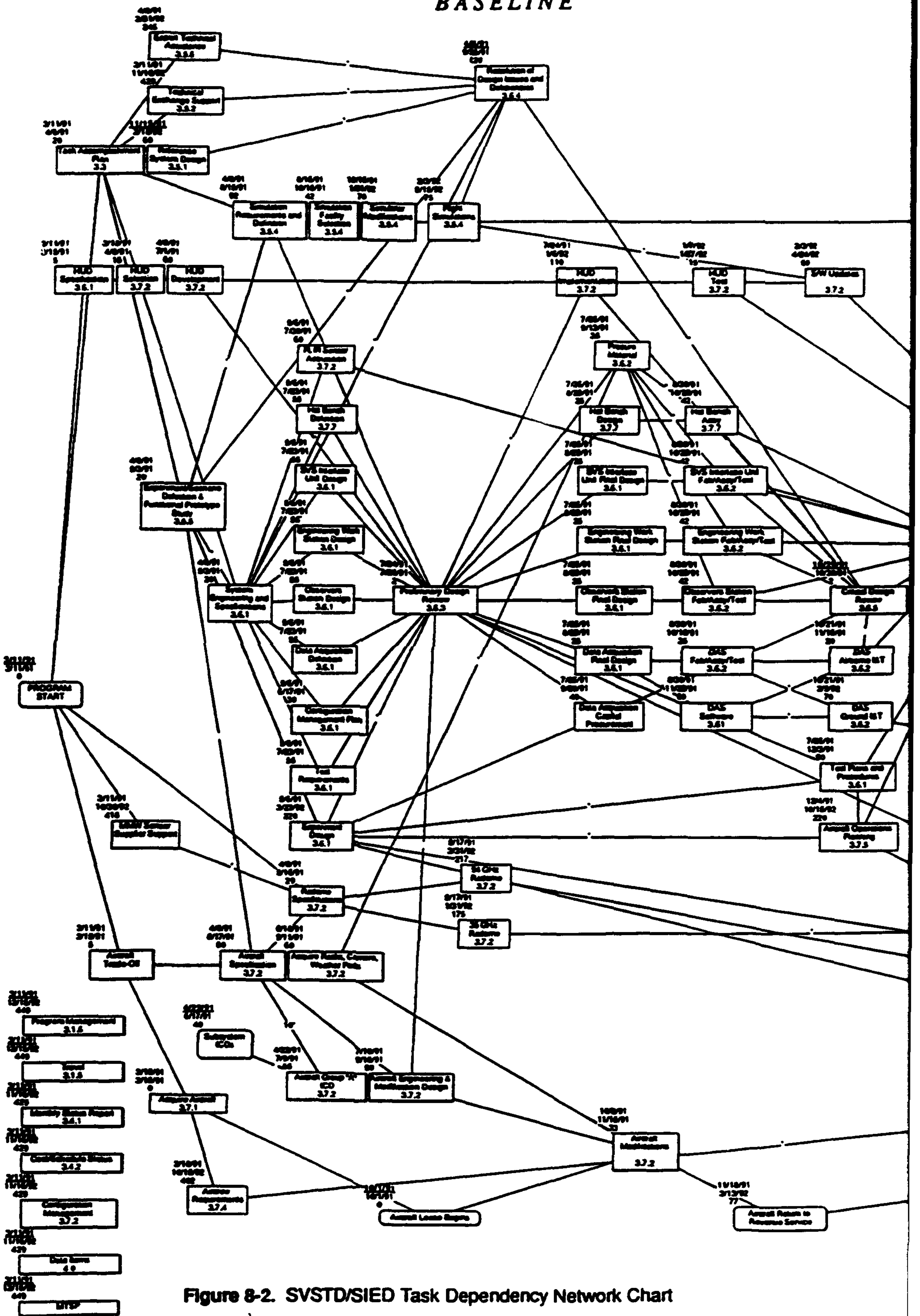

Figure 8-2. SVSTD/SIED Task Dependency Network Chart

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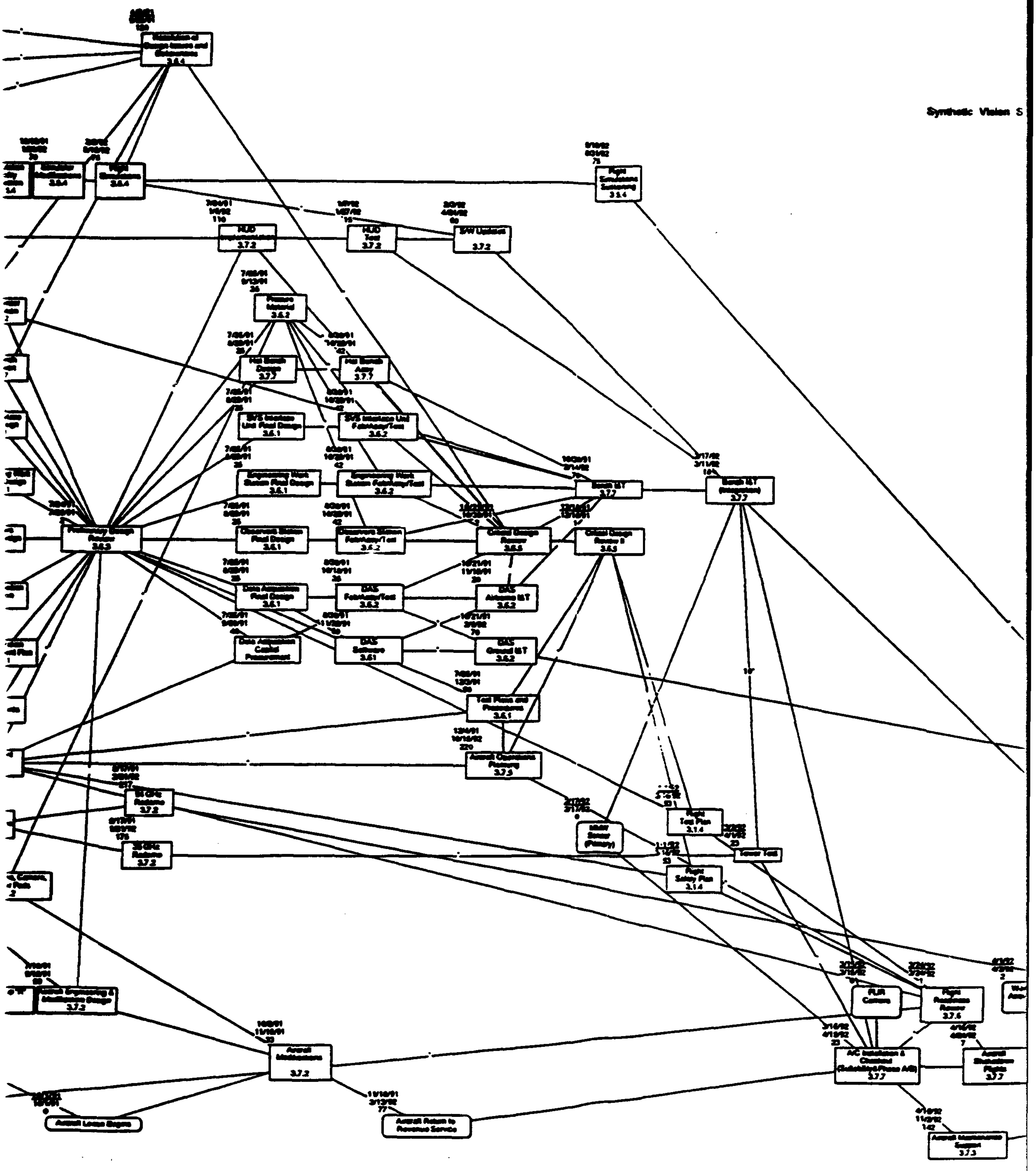
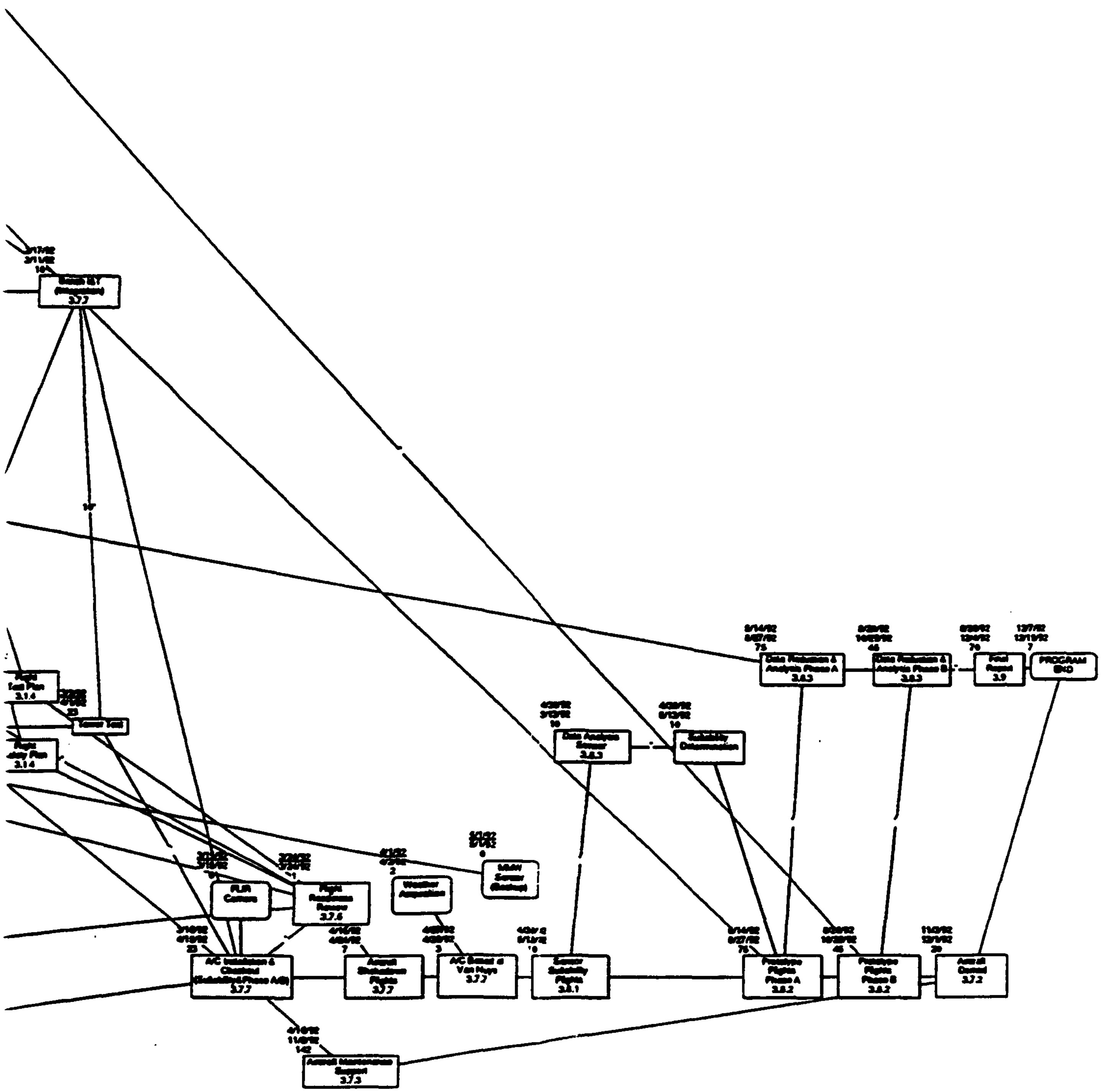


)/SIED Task Dependency Network Chart

Synthetic Vision System Task Dependency Network



Appendix A - SIED WBS TASK DESCRIPTIONS

A. SIED Management

A.1 Program Management

A.1.1 TRW Program Office

MEAD: Establish a TRW SVSTD/SIED Program Office at TRW/MEAD. Dedicate a TRW Program Manager throughout the life of the SIED. Provide guidance, leadership and technical resources to the engineers as required to maintain performance requirements within cost and schedule constraints. Manage all aspects of the SIED's execution.

MEAD: Provide Assistant TRW Program Managers as required to provide the necessary expertise to support the TRW Program Manager for the successful completion of the program tasks in the areas of:

— Functional Prototype System Development

— Aircraft Integration and Flight Test

A.1.2 Cost and Schedule Reporting

MEAD: Establish and maintain budget and task completion tracking to determine earned value for both cost and schedule. Consolidate vendor and subcontractor schedules to assure that all pertinent milestones to determining progress are incorporated into the TRW master schedule. Detail the results monthly in the *Cost/Schedule Status Report* (CDRL Sequence No. A021).

MEAD: Develop a resource allocation methodology and establish a tracking mechanism with sufficient resolution and timeliness to ensure resources are properly rationed to permit achievement of SIED objectives on schedule and within available resources. Report on status of SIED resource allocations monthly in the *Cost/Schedule Status Report* (CDRL Sequence No. A021).

A.1.3 Status Report/Program Plan

MEAD: Track the overall status of the SIED CET. Provide a monthly *Status Report* (CDRL Sequence No. X003) giving sufficient detail that the ability of the CET to meet its goals and objectives within the available resources can be evaluated.

MEAD: Develop a comprehensive *TRW Program Plan* which contains the following:

1. Work Breakdown Structure (WBS) for all SIED elements.
2. Task descriptions of the WBS elements.
3. Schedule planned for execution of WBS elements.
4. Resources allocated to WBS elements.
5. Dependancies and Critical Path analysis of remaining WBS elements.

Maintain the TRW Program Plan as a vehicle to document actual performance and the "Plan-To-Complete" throughout the project's life. Provide updated TRW Program Plans to major vendors and subcontractors and as part of the monthly *Status Report* (CDRL Sequence No. X003).

A.1.4 Risk Management

MEAD: Periodically review all WBS task statements with the cognizant TRW and subcontract personnel for risk identification. Assess each identified risk's probability of occurrence and its potential impact. Determine those risks which may have significant impact on the SIED. Establish a plan to resolve or mitigate such risks and an estimate of the resources required. Decide if the recommended solutions are desirable for implementation. Re-allocate

resources as necessary to implement the required actions. Document the risk, its analysis, and resolution in the *Design Issues and Deficiencies Report* (CDRL Sequence No. X010).

A.2 Travel and ODC

MEAD: Budget and track the costs for SIED travel and Other Direct Costs (ODC).

ALL SUBCONTRACTORS: Budget and track the costs for SIED travel and Other Direct Costs (ODC).

A.3 Configuration Management

MEAD: Prepare a *Configuration Control Plan* (CDRL Sequence No. X009) which details the configuration controls and methods which will be used on the SIED. This document shall provide mechanisms for control of the following:

1. Configuration of the aircraft for each sortie.
2. Configuration management requirements and techniques for hardware and software developed for or used on the aircraft during the SIED.
3. Configuration management requirements and techniques for hardware and software used to process or analyze data taken on the SIED.
4. Interface between aircraft records and SIED configuration management.
5. Central equipment accountability and location records for all bailment, CFE, GFE, or capital equipment used by TRW or its subcontractors.

MEAD: Provide manpower and computing resources required to establish and maintain the SIED configuration in accordance with the approved Configuration Management Plan.

MEAD: Provide configuration management for deliverable equipment, computer codes, and documentation that is in compliance with the SIED Configuration Management Plan. Provide CM coordination to assure that current configurations being provided are in compliance with the approved flight configuration.

A.4 Subcontracts Management

MEAD: Establish and manage the subcontractors, consultants, and vendors making up the SIED team. Establish management methods which will assist in early detection of schedule slippage and/or product non-compliance so that risk management techniques can be applied. Coordinate the updating of subcontract documents and technical direction so that they and the expectations set out in the TRW Program Plan are consistent.

ALL SUBCONTRACTORS: Provide for management of respective efforts under the TRW subcontract requirements including configuration control, documentation, and meeting cost and schedule milestones.

A.5 Program Reviews

A.5.1 Technical Interchange Meetings

MEAD: Plan, schedule, and arrange for hosting of informal Technical Interchange Meetings with the customer and/or subcontractors, consultants, and major vendors.

ALL SUBCONTRACTORS: Provide appropriate support and attendance to informal Technical Interchange Meetings as required.

A.5.2 Formal Reviews

MEAD: Plan, schedule, and host formal reviews of the SIED. These will include a Preliminary Design Review and the Critical Design Review. Tasks associated with this function include conducting the meeting, preparation of briefing materials, presentation of the briefings, and the management of any Review Discrepancies. Technically review and recommend

disposition of each Review Discrepancy submitted.

SVPO: Chair the design reviews. Determine which Review Discrepancies shall be formally submitted to the contractor for comment. Determine the disposition of all Review Discrepancies.

A.5.3 Flight Readiness Reviews

MEAD: Plan, schedule, and host formal Flight Readiness Reviews. The first review is to determine the acceptability of the aircraft, equipment, procedures, and personnel to perform the shakedown and suitability flights. A second review extends the determination of acceptability to the Phase A and Phase B flights. Conduct the meeting, prepare and present briefing materials, and manage any Review Discrepancies.

TBD: Chair the flight readiness reviews. Determine the acceptability of the aircraft for the described operation. Establish any additional requirements which must be met prior to approval being provided.

A.6 Data Items

MEAD: Identify and document internal data pertinent to the SIED. Establish a repository for such data and log it in the *Data Accession List/Internal Data*. (CDRL Sequence No. X001) for quarterly transmittal to the customer.

MEAD: Track and assure that all deliverables stated in the SIED are prepared and delivered to the customer in a timely manner. These may be produced by TRW, their subcontractors, or consultants.

B. System Analysis and Studies

B.1 Operational Scenarios and Experiments

B.1.1 Operational Issues and Criteria

MEAD/Law: Recommend and justify the operational scenarios and experiments that will be the basis for the design, implementation, and execution of the SIED. Select and refine the pertinent underlying issues, including their scope, criterion, and supporting rationale. Optimize this set so that it will be valuable to Government and Industry while remaining within the SIED contractual scope and funding.

MEAD: Maintain the documentation of the SIED operational scenarios and experiments as Appendix B to the *Functional Prototype System Performance Requirements Study* (CDRL Sequence No. X008).

MEAD: Document and maintain the Issues, Criterion, and Rationale results as Appendix B to the *Functional Prototype System Performance Requirements Study* (CDRL Sequence No. X008).

B.1.2 Test Methodology

MEAD/Law: Develop a test methodology that organizes and optimizes the conduct of the flight test program.

MEAD/Hoh: Assist in the development of the test methodology. Develop the portions of test methodology that assures that a confidence factor in the resolution of an issue is established. Provide techniques and controls that allow inconclusive data to be identified early in the test program.

MEAD: Document and maintain the Test Methodology as Appendix A to the *Flight Test Plans* (CDRL Sequence No. X012).

B.1.3 Flight Test Conditions

MEAD/Law: Define the independent test conditions that are required to satisfy the scope of investigation developed for the selected issues. A full description of each test condition, its applicability to the selected issues, and the specific the test values are to be developed.

MEAD: Document and maintain the Independent Flight Test Conditions as Appendix D to the *Functional Prototype System Performance Requirements Study* (CDRL Sequence No. X008).

B.1.4 Flight Test Matrix

MEAD: Prepare a detailed "Flight Test Matrix" which combines the test scope, independent test conditions, and operational considerations into a unified operational flight test requirement document.

MEAD: Implement the Flight Test Matrix as a multi-dimensional data base suitable for personal computer utilization during the flight test. Documentation should include description of the data base, instruction for its use, and a readable version of the data base contents expressed in a series of two-dimensional (tabular) views through the data base.

MEAD: Document and maintain the Flight Test Matrix as both a physical data base and as Appendix B to the *Flight Test Plans* (CDRL Sequence No. X012).

B.1.5 Data Analysis Requirements

MEAD/Law: Establish the data analysis approach that will be used to determine if each issue's criterion(s) have been met. Determine the types and formats of final data products that will be required to accomplish the data analysis. Optimize the analysis and data processing requirements to fit within the SIED schedule requirements. Provide capability which will allow the current configuration data to be up-loaded and then recorded into the "header" of each data acquisition file.

MEAD: Document and maintain the Flight Test Data Analysis requirements as Appendix E to the *Functional Prototype System Performance Requirements Study* (CDRL Sequence No. X008).

B.1.6 Data Elements and Sources

MEAD/Law: Determine the data elements and their corresponding aircraft sources that are required to satisfy the Data Analysis Requirements. Identify requirements for measurement accuracy, update rate, data latency, and any element-to-element timing that must be considered.

MEAD: Document and maintain the Data Elements and Data Sources as Appendix F to the *Functional Prototype System Performance Requirements Study* (CDRL Sequence No. X008).

B.1.7 Flight Test Resource Management

MEAD/Law: Utilizing the Flight Test Matrix and data analysis requirements, develop a traffic model for the flight test portion of the SIED. This should provide estimates of manpower and direct costs including:

1. Aircraft ground and flight time.
2. Flight Crew Costs.
3. Ferry and TDY costs.
4. Reserves For No-Flight Periods
5. Data Acquisition Time and Required Supplies
6. Data Reduction Time and Required Supplies
7. Data Analysis and Report Time

MEAD/Law: Iterate the definition of SIED objectives and the underlying issues, testing, and analysis against the traffic model's cost and schedule predictions as required to define a flight test program that is within the SIED's schedule and resources.

MEAD/Law: Provide for the continuing tuning of the Functional Prototype System Performance Requirements tasks as actual capabilities and data replace planned functions throughout the SIED's life to maximize total knowledge returned without exceeding available resources.

B.2 Data Acquisition and Reduction

MEAD: Develop detailed data acquisition and reduction software requirements based upon the data analysis and data elements and sources established above.

B.3 Data Analysis/Documentation

MEAD: Manage the data analysis and documentation effort, including the scheduling and scope of data analysis to be performed by TRW, JTD, and GTRI.

MEAD: Integrate weather data received from the JTD, Inc. weather sensor package with the DAS data. The correlation should be made using a common time clock recorded by both systems and should automatically be made for all flight data processed.

MEAD: Perform the analysis of the FPSVS data.

B.4 Final Report

MEAD: Lead in the preparation of the Final Report.

MEAD: Publish the aggregate results of the SIED in the *Final Report* (CDRL Sequence No. A005) and its appendices.

B.5 GTRI Subcontract

GTRI: Provide attendance, support, or presentations as requested by TRW in the conduct of

informal and formal reviews. These will include Technical Interchange Meetings, Preliminary and Critical Design Reviews, and Flight Readiness Reviews.

GTRI: Provide configuration management for deliverable equipment, computer codes, and documentation that is in compliance with the SIED Configuration Management Plan. Provide CM coordination to assure that current configurations being provided are in compliance with the approved flight configuration.

GTRI: Provide the facilities and handling to process MMW sensor data that will be proprietary and for non-proprietary FPSVS data.

GTRI: Perform the analysis for all proprietary MMW sensor data and for selected analysis on non-proprietary FPSVS data. This analysis is to characterize the performance of both the radar sub-unit and the overall sensor (including image processing) system.

GTRI: Provide test requirements required for MMW Radar performance evaluation. Review and comment on the resulting procedures.

GTRI: Participate in the development and preparation of the Final Report as designated by TRW and/or appropriate. Plan to provide a section for covering services provided to the SIED.

B.6 JTD Subcontract

JTD: Provide attendance, support, or presentations as requested by TRW in the conduct of informal and formal reviews.

JTD: Provide configuration management for deliverable equipment, computer codes, and documentation that is in compliance with the SIED Configuration Management Plan. Provide CM coordination to assure that current configurations being provided are in compliance with the approved flight configuration.

JTD: Provide a system for the collection of weather data, including the real time processing of the raw sensor data into usable parameters.

JTD: Verify mechanical interface of pylon/pod to weather sensors. Mechanically install sensors.

JTD: Perform final continuity and ground checks of wiring for weather sub-system components. Perform power and ground checks. Install weather subsystem and verify operation in the aircraft.

JTD: Process the weather data so that total water content and particle size distribution statistics exist showing the amounts to the runway touchdown from each point along the approach path. Correlation to existing data should be done through use of a common time clock. Provide the processed weather data in both hardcopy and in floppy disk format.

JTD: Provide technical support during the system integration and checkout period.

JTD: Test and verify the operation of the weather sensors.

JTD: Participate in the development and preparation of the Final Report as designated by TRW and/or appropriate. Plan to provide a "Equipment Evaluation" section for equipment or services provided to the SIED.

B.7 Simulation Studies

B.7.1 Simulation Objectives Definition

MEAD: Identify the Functional Prototype Synthetic Vision System design issues that require simulation support efforts. Define the scope and criterion for each issue identified.

MEAD/Law: Identify SIED issues which are either not suitable for in-flight evaluation or especially lend themselves to resolution using low-realism MMW sensor simulations. Define the scope and criterion for each issue identified. Assist in the definition of a simulation program to

evaluate those issues including the data acquisition and data reduction/analysis requirements.

MEAD/Hoh: Document and maintain identified simulation objectives in the *Simulation Plans* (CDRL Sequence No. X006).

MEAD/Hoh: Develop a simulation plan capable of achieving the identified objectives. This should include the following:

1. Define environments and tasks which must be supported by the simulation to allow each objective to be investigated, developed, or verified as appropriate.
2. Identify data (subjective and/or quantitative) that needs to be acquired to determine if each objective as been adequately met. Determine any data reduction, preparation, or formatting that may be required before it can be effectively used.
3. Design of specific flight scenarios, independent test conditions, and maneuvers needed to support each objective's achievement.
4. Determination of the pilot (test subject) mix and the test repetition needed to assure reasonable confidence in the results.
5. Optimize simulator usage by identifying where the data elements for multiple objectives/experiments can be combined into a single task, scenario, or maneuver. Develop the simulation test matrix which results.
6. Establish the pilot familiarization required.
7. Establish the specific pilot instructions, test conductor scenario, and debrief areas for each simulation objective.
8. Organize the resultant simulation tasks into a logical progression that will be presented to the pilot for execution.
9. Summarize the simulation details in a simulation test matrix which allows the scope and completion status of the simulation task to be determined.

MEAD/Hoh: Document and maintain the simulation plan into the *Simulation Plans* (CDRL Sequence No. X006) document.

B.7.2 Facility Selection

MEAD: Select a simulation facility which best optimizes the achievement of the simulation objectives within the available schedule and resource constraints. This is expected to include:

1. Preparation and submission of a Request For Proposal to simulation facilities. This would be accompanied with informational copies of the current Simulation Plan to assure that the simulation facilities are able to fully understand and assist in achieving its objectives.
2. On-site survey and evaluation of their existing capabilities and approach to implementing any modifications required to support the simulation plan.
3. Iteratively refine the simulation requirements and scope in the light of the capabilities existing and/or proposed at facilities meeting the basic requirements.
4. Recommend the most cost effective total solution(s) of simulation requirements, scope, and modifications for each potential facility.

MEAD: Justify a directed or limited procurement, or establish the specific requirements and evaluation criteria for a competitive procurement. Develop and perform a procurement cycle to select and contract with the simulation facility.

B.7.3 Facility Preparation

MEAD: Assure that current provisions for cockpit controls and mode selection are provided to the simulation facility for incorporation.

MEAD: Oversee the simulator modifications, and perform acceptance of the resulting simulation facility.

B.7.4 Simulation Operations

MEAD: Provide a Simulation Test Director who will direct and run the simulation operations. Responsibilities will include:

1. Coordination with Facility and Test Subjects for simulation time.
2. Conduct pre-simulation briefings and/or training on advanced equipment and concepts.
3. Providing guidance and instruction to test subjects during familiarization periods.
4. Presenting the detailed scenarios, conditions, and pilot instructions for each simulation run.
5. Annotate each run's record with pertinent data and comments as necessary.
6. Assure that the test subject's qualitative evaluation is correctly and completely obtained and documented.
7. Manage logistics of collecting simulation data and organizing it.

MEAD: Provide for the processing of analytical data received from the simulation facility.

MEAD: Perform analysis of the data received and determine results achieved.

COMMENT: This may not be required on many design engineering questions which are to be resolved while at the simulator.

MEAD: Document the simulator operations, data, and results of analysis in the *Simulation Results* (CDRL Sequence No. X007) document.

B.8 Simulation Subcontractor

B.8.1 Facility Preparation

SIM: Perform the modifications and preparation of the simulation facility as specified to support the SVS Simulation effort. Prepare a Simulator Acceptance Plan as specified in the contractual documents.

B.8.2 Simulation Operations

SIM: Operate simulation facility during SIED simulation periods.

SVPO: Identify and make available the evaluation pilots for the simulation studies.

B.9 Engineering Plans and Schedule Development

B.9.1 Flight Test Plan

MEAD: Generate a Flight Test Plan to satisfy the Flight Test Matrix. Add the operational limitations and necessities of the real world to the idealized test sequences defined in the test matrix. Document should support initial planning of the test matrix resource allocation and should include:

A. Expected basing and operating sites.

B. Analysis of ferry overhead and strategies for controlling it.

C. Implementation of weather forecasting capability for both "next sortie" and current (in-flight) sortie operations.

D. Logistic planning and budget allocations.

E. Procedures for special ATC/FAA/Airport operational clearances and/or handling.

F. Airport Fixed Base Operators established as technically and financially acceptable to service and house the aircraft.

G. Crew Call Out procedures.

H. Estimates of total flying time and total ancillary expenses to accomplish the flight test matrix objectives.

MEAD: Document the results as the *Flight Test Plans* (CDRL Sequence No. X012) document.

B.9.2 Safety Plan

MEAD/Law: Develop a safety plan which achieves flight safety through overall integration of hardware architecture, implementation features and capabilities, training, procedures, flight/mission rules, and flight readiness reviews. The plan should include the following:

1. Safety Requirements.
2. Hazard Analysis of resulting aircraft including SIED modifications and added airborne systems, crew manning changes, hard landings, and operations below existing minima.
3. Rationale why the implemented safety system does not require a Failure Mode and Effects Analysis to demonstrate acceptable safety.
4. Rationale why the implemented safety system does not require a Reliability Analysis to demonstrate acceptable safety.
5. Procedures for an objective, independent review of readiness for flight.

MEAD: Document the safety plan in the *Flight Safety Plan* (CDRL Sequence No. X002) document.

C. Functional Prototype SVS System Design

C.1 Requirements, System Engineering, and Specifications

MEAD: Provide overall engineering and integration leadership for the Functional Prototype Synthetic Vision System (FPSVS) developed under the SIED.

C.1.1 System Definition

MEAD: Develop the *FPSVS Specification* using inputs and requirements developed in the System Analysis tasks.

C.1.2 Head Up Display

C.1.2.1 Specification

MEAD: Develop a Head Up Display Specification that includes the Head Up Display (HUD) and associated HUD Computer. This specification shall cover the following:

1. RS-170 Raster Image capability for FPSVS sensors.
2. Stroke written symbology capabilities.
3. Interface to the Head Down Display subsystem.
4. Interface to the cabin display subsystems.
5. Interface to aircraft and systems.

C.1.2.2 Technical Selection

MEAD/Law: Evaluate proposed HUD systems. Recommend and justify selection of HUD.

C.1.2.3 Technical Support

MEAD: Provide any supporting elements that are essential for design verification and subsystem testing prior to integration.

C.1.3 Head Down Display

C.1.3.1 Specification

MEAD: Develop requirements for a suitable display for installation in the co-pilot's ADI EFIS and center Weather Radar/EICAS positions. Establish criteria for reverting the positions back to normal operations.

C.1.3.2 Technical Selection

MEAD/Law: Evaluate proposed display units. Provide recommendation on sources and justification for restricted or sole source procurement.

C.1.4 Data Acquisition System

C.1.4.1 Definition

MEAD: Define the configuration and capabilities of the Data Acquisition System (DAS) from the requirements specified in the *Functional Prototype System Performance Requirements Study*. The DAS must complement the "MMW Sensor Data Collection" systems provided by each MMW sensor vendor. The combined capabilities should support the following:

1. Gathering and recording of "proprietary" sensor performance data.
2. Gathering and recording of public data which is required to satisfy the SIED objectives, issues, and experiments. This includes video of the final imagery output from each sensor, with or without the HUD symbology overlay.

C.1.5 Hot Bench

MEAD: Define requirements for a "Hot Bench" providing an integration and test facility for the

FPSVS. Major segments include:

1. Mechanical fixtures allowing access to equipment while providing wiring interface and cooling.
2. Interface simulators for ARINC 429, analog, and discrete signals used by the flight system.
3. Access to all Group A interconnect wiring via junction blocks or test points.

C.2 Hardware Design

C.2.1 Head Down Display

C.2.1.1 HDD Electrical Design

TBD: Perform the detailed design to integrate the FPSVS Head Down Displays with both the HUD Computer and the standard aircraft EFIS environment.

C.2.2 Data Acquisition System

MEAD: Manage the design and implementation of a data acquisition and data reduction system for the SIED.

MEAD: Design the FPSVS data acquisition and ground playback/analysis systems. Design the aircraft electrical interface and protocols.

C.2.3 Test Director Work Station

MEAD: Design the Flight Test Director's Work Station. Provide for the monitoring of all flight test experiments and sensors as well as suitable communication capability as specified in the *Functional Prototype System Performance Requirements Study*.

C.2.4 Test Engineer Work Station

MEAD: Design the Test Engineer Work Station. Provide for the control and monitoring of the Data Acquisition System and for an interface with the HUD Computer for mode and control setups. Provide for the monitoring of sensors and HUD/HDD operation as well as suitable communication capability as specified in the *Functional Prototype System Performance Requirements Study*.

C.2.5 Observers Work Station

MEAD: Design the Observers Work Station. Provide for the monitoring of all flight test experiments and sensors as well as suitable communication capability as specified in the *Functional Prototype System Performance Requirements Study*.

C.2.6 FPSVS Interface Unit

MEAD: Design and develop the FPSVS Interface Unit. Provide for the signal conditioning, protocol conversion, and signal buffering required between the sensors, work stations, and data acquisition system.

C.2.7 Hot Bench

MEAD: Design the Hot Bench.

C.3 Software Design

C.3.1 Data Reduction System

MEAD: Procure, modify, or develop the necessary data reduction software to process flight data into a format suitable for data analysis and evaluation. The requirements for this package are documented in the *Functional Prototype System Performance Requirements Study*.

C.3.2 Data Acquisition System

MEAD: Design, implement, and test data acquisition software.

MEAD: Design, implement, and test the in-flight monitoring and quick-look software. This shall be capable of checking the data being recorded and providing necessary near-real-time display of parameters from the data acquisition data stream.

C.4 Mechanical Design

MEAD: Design aircraft rack panels, shelves, layout, and vibration/shock mount installations.

MEAD: Specify and procure required panels, controls, displays, shelves, and vibration/shock mount materials.

C.5 Implementation and Integration

C.5.1 Head Down Display

C.5.1.1 HDD Acquisition

MEAD: Acquire two head down display units with two sets of mating connectors for each unit. Establish maintenance accessibility and engineering support for non-standard components.

C.5.1.2 HDD Integration

MEAD: Provide unit(s) to GEC for testing of HUD Computer interface.

MEAD: Provide unit(s) to aircraft modifier to assure mechanical fit.

C.5.2 FLIR

C.5.2.1 FLIR Acquisition

MEAD: Acquire the selected FLIR sensor.

C.5.3 MMW Sensor Racks

MEAD: Prepare and deliver two airworthy 19" equipment racks, complete with Gulfstream II seat rail attachments to Lear Astronics.

TBD: Prepare and deliver one airworthy 19" equipment racks, complete with Gulfstream II seat rail attachments to Honeywell.

C.5.4 Test Director Work Station

MEAD: Fabricate, procure, and integrate the Flight Test Director's Work Station. Test work station wiring and function to the Class A wiring interface. Deliver to the Hot Bench for FPSVS integration testing.

C.5.5 Test Engineer Work Station

MEAD: Fabricate, procure, and integrate the Test Engineer's Work Station. Test work station wiring and function to the Class A wiring interface. Deliver to the Hot Bench for FPSVS integration testing.

C.5.6 Observers Work Station

MEAD: Fabricate, procure, and integrate the Observers Work Station. Test work station wiring and function to the Class A wiring interface. Deliver to the Hot Bench for FPSVS integration testing.

C.5.7 FPSVS Interface Unit

MEAD: Fabricate, install with Class B wiring in racks, and test the FPSVS Interface Unit. Deliver to the Hot Bench for FPSVS integration testing.

C.5.8 Data Acquisition and Reduction System

MEAD: Procure and assemble the Data Acquisition System using industry standard computer

architectures from both TRW capital equipment and program funded application specific software and hardware. Design and implement the aircraft electrical interface and protocols.

MEAD: Establish a data processing and reduction capability for the FPSVS and simulation data acquisition system(s). Provide computing resources and support manpower as required throughout the SIED period.

MEAD: Validate the correct operation of both the data acquisition system and the data reduction system.

C.6 Hot Bench

MEAD: Fabricate and assemble the Hot Bench. Perform continuity wiring checks followed by power on and ground checks.

C.6.1 Hot Bench Integration Test

MEAD: Develop integration and test plan for Hot Bench integration. This should include clear division of responsibility for initial power-up of each subcontractor/vendor's equipment being integrated.

MEAD: Prepare test plans and procedures to verify and validate equipment operation at the Hot Bench checkout facility.

MEAD: Provide the Hot Bench and supporting facility complete with appropriate power and an aircraft interface simulator for ARINC 429 and analogs. Provide engineers and support technicians as required during the Hot Bench utilization.

MEAD: Provide the flight FPSVS equipment including the data acquisition system, work stations, and interface unit.

TBD: Provide Head Down Display unit to Hot Bench Integration and Checkout. Perform backup verification of wiring and power and ground checks. Install HDD (FPSVS) subsystem into Hot Bench and assist in debugging its operation.

MEAD: Run integration test at the Hot Bench facility. Assure proper operation of all connected equipment prior to aircraft integration.

MEAD: Provide for data reduction system support for the Bench Integration and Test to assist in the integration.

C.6.2 Hot Bench System Test and Evaluation

MEAD: Develop a system test and evaluation procedure.

MEAD: Validate the Data Acquisition System operation.

MEAD: Validate the correct rendering of data through the Data Reduction System.

MEAD: Develop static measurements of system performance that can be repeated at the aircraft integration to assure proper system performance. This may primarily involve the data acquisition system.

C.7 Lear Astronics Subcontract

LEAR: Provide attendance, support, or presentations as requested by TRW in the conduct of informal and formal reviews. These will include Technical Interchange Meetings, Preliminary and Critical Design Reviews, and Flight Readiness Reviews.

LEAR: Provide initial and updated detailed ICD information on the Lear Astronics 94 GHz MMW subsystem for inclusion in the Master ICD. Review and comment on Master ICD to assure that its data is correct and technically acceptable to Lear Astronics.

LEAR: Provide configuration management for deliverable equipment, computer codes, and documentation that is in compliance with the SIED Configuration Management Plan. Provide

CM coordination to assure that current configurations being provided are in compliance with the approved flight configuration.

LEAR: Provide technical assistance in determination of design and sources for MMW radome materials.

LEAR: Provide MMW sub-system to TRW for integration and test phases and then flight operations. Provide two sets of mating connectors.

LEAR: Install MMW equipment and "Group B" wiring into equipment racks. Debug and validate operation. Deliver equipment for installation on aircraft.

LEAR: Provide technician and engineering support during aircraft installation and test.

LEAR: Provide specifications and basic capabilities of the MMW Sensor Data Collection systems being supplied with the sensor.

LEAR: Provide MMW Sensor to Hot Bench Integration and Checkout. Perform backup verification of wiring and power and ground checks. Install MMW subsystem into Hot Bench and assist in debugging its operation.

LEAR: Assist in developing test plans and procedures for MMW sub-system checkout at the Hot Bench facility.

LEAR: Develop a detailed procedure for installation into the aircraft.

LEAR: Validate MMW mounting provisions including mechanical interface with radome and MMW antenna.

LEAR: Perform final verification of wiring for MMW Radar sub-system components. Perform power and ground checks. Electrically install MMW subsystem and verify operation.

LEAR: Provide technical support during the system integration and checkout period.

LEAR: Test and verify the operation of the MMW Sensor during the Shakedown Flight Tests.

LEAR: Provide a MMW Sensor Operator for flights involving the Lear Astronics MMW Radar during Suitability Flight Test.

LEAR: Provide a MMW Sensor Operator for flights involving the Lear Astronics MMW Radar during Phase A Flight Test.

LEAR: Provide assistance on an "As Required Basis" during the Phase B flight test period.

LEAR: Provide definition of internal data formats and encoding methods to Georgia Tech Research Institute (GTRI). Establish any needed proprietary relationship with GTRI.

LEAR: When requested by TRW, make recordings of raw sensor data and all pertinent calibration and set-up data available to GTRI for analysis. This data may be proprietary to Honeywell, GTRI, and the government.

LEAR: Lead in the establishment of FCC approval to operate the sensor's transmitter in the areas of planned operations and over the scheduled period of operation. Continue to coordinate with the FCC for any revisions or extensions of the transmitter approval.

C.8 GEC Subcontract

GEC: Provide attendance, support, or presentations as requested by TRW in the conduct of informal and formal reviews. These will include Technical Interchange Meetings, Preliminary and Critical Design Reviews, and Flight Readiness Reviews.

GEC: Provide initial and updated detailed ICD information on HUD subsystem for inclusion in the Master ICD.

GEC: Provide initial and updated detailed installation and/or internal design data so that a Head Down Display ICD can be established for inclusion in the Master ICD.

GEC: Review and comment on Master ICD to assure that its data is correct and technically acceptable to GEC.

GEC: Provide configuration management for deliverable equipment, computer codes, and documentation that is in compliance with the SIED Configuration Management Plan. Provide CM coordination to assure that current configurations being provided are in compliance with the approved flight configuration.

GEC: Provide technical expertise and engineering support to simulation effort in support of HUD and HUD Computer. Provision support for HUD Computer software revisions, especially in the area of decluttering and symbology set tuning.

COMMENT: Within the limits of proprietary data, provide required technical details on the characteristics of the aircraft HUD and the shape and movement of certain HUD symbology may be required.

Alternatively, GEC may be requested to supply actual hardware and software which will be integrated into the simulation facility.

GEC: Design, build, and test the HUD subsystem. Provide TRW with notification of when supporting elements are needed for design verification and test.

GEC: Measure, evaluate, and analyze mounting for HUD in the G-II aircraft. Design a mounting tray(s) which will interface between the aircraft and the HUD Display Unit, Electronics Unit, and HUD Computer. Build/procure the mounting trays and associated mating connectors. Provide to TRW for installation in the aircraft.

GEC: Test electrical interface to Head Down Display units. Tune the HUD Computer symbol generator software to assure that stroke symbology is properly presented. Establish raster display output so that the stroke correctly overlays the raster (same as HUD).

GEC: Provide HUD subsystem to Hot Bench Integration and Checkout. Perform backup verification of wiring and power and ground checks. Install HUD subsystem into Hot Bench and assist in debugging its operation.

GEC: Assist in developing test plans and procedures for HUD sub-system (including Head Down Display interface) checkout at the Hot Bench facility.

GEC: Provide technical data and engineering assistance to the aircraft engineering vendor/modifier to assure that the HUD Display airframe attach points are properly located, evaluated for loads, designed, and verified for flight stresses.

GEC: Provide the HUD hardware and technical support during the integration of the HUD into the Hot Bench.

GEC: Develop a detailed installation procedure for the HUD.

GEC: Perform final installation and boresight of the HUD Display Tray.

GEC: Perform final verification of wiring for HUD sub-system components. Perform power and ground checks. Install HUD subsystem and verify operation in the aircraft.

GEC: Provide technical support during the system integration and checkout period.

GEC: Provide assistance on an "As Required Basis" during the Phase A flight test period.

GEC: Provide assistance on an "As Required Basis" during the Phase B flight test period.

C.9 Kodak Subcontract

KODAK: Provide attendance, support, or presentations as requested by TRW in the conduct of informal and formal reviews. These will include Technical Interchange Meetings, Preliminary and Critical Design Reviews, and Flight Readiness Reviews.

KODAK: Provide initial and updated detailed ICD information on FLIR subsystem for inclusion in the Master ICD. Review and comment on Master ICD to assure that its data is correct and

technically acceptable to KODAK.

KODAK: Provide configuration management for deliverable equipment, computer codes, and documentation that is in compliance with the SIED Configuration Management Plan. Provide CM coordination to assure that current configurations being provided are in compliance with the approved flight configuration.

KODAK: Provide technical assistance in determination of design and sources for FLIR window materials.

KODAK: Provide FLIR sub-system to TRW for integration and test phases and then flight operations. Provide two sets of mating connectors.

KODAK: Provide FLIR to Hot Bench Integration and Checkout. Perform backup verification of wiring and power and ground checks. Install FLIR subsystem into Hot Bench and assist in debugging its operation.

KODAK: Provide technical support during the system integration and checkout period.

KODAK: Provide assistance on an "As Required Basis" during the Phase A flight test.

KODAK: Provide assistance on an "As Required Basis" during the Phase B flight test period.

C.10 Honeywell Support

HONEYWELL: Provide attendance, support, or presentations as requested by TRW in the conduct of informal and formal reviews. These will include Technical Interchange Meetings, Critical Design Review, and Flight Readiness Reviews.

HONEYWELL: Provide initial and updated detailed ICD information on the Honeywell 35 GHz MMW subsystem for inclusion in the Master ICD. Review and comment on Master ICD to assure that its data is correct and technically acceptable to Honeywell.

HONEYWELL: Provide configuration management for deliverable equipment, computer codes, and documentation that is in compliance with the SIED Configuration Management Plan. Provide CM coordination to assure that current configurations being provided are in compliance with the approved flight configuration.

HONEYWELL: Provide MMW sub-system to TRW for integration and test phases and then flight operations.

HONEYWELL: Install MMW equipment and "Group B" wiring into equipment racks. Debug and validate operation.

HONEYWELL: Provide MMW Sensor to Hot Bench Integration and Checkout. Perform backup verification of wiring and power and ground checks and assist in debugging its operation.

HONEYWELL: Deliver equipment to the installation site and provide technician and engineering support during aircraft installation and test. Perform final verification of wiring for MMW Radar sub-system components. Perform power and ground checks. Electrically install MMW subsystem and verify operation.

HONEYWELL: Assist in developing test plans and procedures for MMW sub-system checkout at the Hot Bench facility.

HONEYWELL: Assist in the development of a detailed procedure for installation into the aircraft.

HONEYWELL: Test and verify the operation of the MMW Sensor during the Shakedown Flight Tests.

HONEYWELL: Provide a MMW Sensor Operator for all Suitability flights.

HONEYWELL: Provide a MMW Sensor Operator for all Phase A flights.

HONEYWELL: Provide assistance on an "As Required Basis" for all Phase B flights.

HONEYWELL: Provide definition of internal data formats, top level signal processing and algorithms, and the data collection format and encoding methods to Georgia Tech Research Institute (GTRI). Establish any needed proprietary relationship with GTRI.

HONEYWELL: Make selected recordings of raw sensor data and all pertinent calibration and set-up data available to GTRI for analysis. This data may be proprietary to Honeywell, GTRI, and the government.

HONEYWELL: Lead in the establishment of FCC approval to operate the sensor's transmitter in the areas of planned operations and over the scheduled period of operation. Continue to coordinate with the FCC for any revisions or extensions of the transmitter approval.

HONEYWELL: Review and provide comments to the development of the GTRI Final Report.

HONEYWELL: Provide inputs, review, and provide comments to the development of the TRW Final Report.

D. Aircraft Preparation

D.1 Specifications and Acquisition

D.1.1 Test Aircraft

MEAD: Develop a detailed specification for the aircraft configuration required for the SIED flight test program. It will include:

1. Standard (Part 91) Avionics to be installed in basic aircraft.
2. FPSVS power requirements.
3. Circuit Breaker Installation
4. Avionics Monitoring or Break-in Points
5. Weight and C.G. Constraints
6. Requirements to Accommodate FPSVS Experimental Equipment

MEAD: Select Aircraft for use in the SIED flight test program.

D.1.2 FLIR Sensor

MEAD: Develop a FPSVS FLIR Specification. This specification shall cover the following:

1. RS-170 Raster Image capability.
2. Mounting Requirements
3. Environmental Requirements imposed by the unpressurized, unconditioned radome environment.
4. Field of View requirements that will match the MMW Sensors.
5. Electrical adjustment capability of image data within the raster sweep so that scenes from the FLIR can be adjusted to overlay the exact display (not just the boresighted center) of the MMW sensor and outside scene.
6. Operational Restrictions (if any) and time from turn on to full operation.

MEAD: Evaluate proposed FLIR systems. Recommend and justify selection of FLIR.

D.2 Raleigh Jet Subcontract

RALEIGH JET: Provide attendance, support, or presentations as requested by TRW in the conduct of informal and formal reviews. These will include Technical Interchange Meetings, Preliminary and Critical Design Reviews, and Flight Readiness Reviews.

RALEIGH JET: Provide Gulfstream II serial number 5 to the SIED flight test program. The aircraft shall be provided with the following standard avionics:

1. EFIS - Honeywell 5-tube EDZ-805
2. Inertial - Litton LTN-92, quantity two.
3. DADC - Honeywell ADZ-800, quantity one.
4. Radar Altimeter - Collins ALT-55B, quantity one.
5. Weather Radar - Honeywell WC-650, quantity one.
6. VHF Nav - Collins VIR-30, quantity two.
7. DME - Collins DME-42, quantity one.
   DME - Collins DME-40, quantity one.
8. ADF - Collins ADF-60A, quantity two.

9. Flight Director - Honeywell FZ-500, quantity two.

RALEIGH JET: Provide the following as part of the lease:

1. Installation of minimum required standard (Part 91) avionics.
2. Hangaring when based at Van Nuys, Ca.
3. Insurance for liability and hull damage.
4. Operational Weather Data from Universal Weather.
5. Flight and ground support crews.
6. Additional items as specified in the aircraft contract SOW.

RALEIGH JET: Provide lead test subject(s) who will provide continuity from the simulation studies to the actual flight operations.

RALEIGH JET: Provide configuration management for deliverable equipment, computer codes, and documentation that is in compliance with the SIED Configuration Management Plan. Provide CM coordination to assure that current configurations being provided are in compliance with the approved flight configuration.

RALEIGH JET: Make available necessary aircraft records to initialize the SIED configuration mangement effort. Provide controls on physical aircraft access and inspector services to assure that aircraft records reflect the aircraft configuration. Provide interface with SIED CM to assure that aircraft configuration conforms to the current design. Maintain physical control and updating of aircraft records (installation/removal sheets, weight and balance, squawk/maintenance actions, etc.) throughout the SIED.

RALEIGH JET: Provide support in the development of the Flight Test Plan. Lead in the establishment of aircraft handling, service, and operations.

RALEIGH JET: Provide support for special weather data and forecast requests as made by TRW.

RALEIGH JET: Assist in development of the Safety Plan. Lead in the development of training, procedures, and flight/mission rules requirements. Review and concur on all aspects of Hazard Analysis, and FMEA and RA waiver rationales.

RALEIGH JET: Provide aircraft support during the system integration and checkout period. Provide a hangar facility and necessary power.

RALEIGH JET: Lead in the application for experimental operations certificate. Assume responsibility for Operational aspects of experimental certificate application.

RALEIGH JET: Review and concur on all operational procedures for safety and efficiency of aircraft usage.

RALEIGH JET: Provide the modified G-II aircraft complete with a fully qualified Captain rated on the GII aircraft with instructor rating. Perform the tasks and responsibilities of Pilot-In-Command.

RALEIGH JET: At both "home base" and TDY operations provide a plane captain qualified on the G-II to manage ground pre-flight and post-flight operations.

RALEIGH JET: The Pilot-In-Command for each sortie shall participate in the sortie planning and solely determine its acceptability in terms of flight safety and compliance to the operating certificate and rules. He shall retain all responsibilities and authority of the Pilot-In-Command during the flight.

RALEIGH JET: Provide aircraft and crew for one or more flights (as required) to check the operation of the aircraft.

RALEIGH JET: Verify the correct operation of the aircraft's avionics including any FPSVS specific equipment installed at this time.

RALEIGH JET: Provide the aircraft and crew for two planned suitability flight phases consisting of a total of six to ten flights (with time for data analysis between them).

RALEIGH JET: Provide the aircraft and crew for the Phase A flight Test Period. Basing will include both "Home" and "TDY".

RALEIGH JET: Provide the aircraft and crew for the Phase B flight Test Period. Basing will include both "Home" and "TDY".

D.3 Midcoast Aviation Subcontract

MIDCOAST: Provide attendance, support, or presentations as requested by TRW in the conduct of informal and formal reviews. These will include Technical Interchange Meetings, Preliminary and Critical Design Reviews, and Flight Readiness Reviews.

MIDCOAST: Establish and maintain a separate history of the experimental modifications made to the Gulfstream II airplane which are to be removed at the end of the SIED.

MIDCOAST: Provide configuration management for deliverable equipment, computer codes, and documentation that is in compliance with the SIED Configuration Management Plan. Provide CM coordination to assure that current configurations being provided are in compliance with the approved flight configuration.

D.3.1 Aircraft (Group A) Wiring

MIDCOAST: Design the wiring runs, harness, and feed-through/connector points for all Group A wiring using the Master ICD as the source document. These are to be treated as spare wires to existing wiring and will not be removed when the aircraft is returned to Part 91/135 service. Allocate aircraft power feeds and circuit protection to support the FPSVS electrical installation.

D.3.2 Aircraft Power

MIDCOAST: Provision for additional 115vac power at both 60 Hz and 400 Hz, including appropriate bussing and circuit protection.

MIDCOAST: Maintain aircraft power loading document to show requirements of FPSVS installation. Maintain aircraft weight and c.g. documents.

D.3.3 Aircraft Mechanical Design

MIDCOAST: Perform the mechanical design of the forward bulkhead mounting to accommodate the weather radar, either Lear Astronics or Honeywell MMW sensor, FLIR sensor, and relocation (out of radome volume) of the existing Glideslope receiving antenna.

MIDCOAST: Measure, evaluate, and analyze mounting for the Lear Astronics MMW Antenna and RF Electronics in the G-II aircraft. Design the mounting brackets and tray(s) which will interface between the aircraft forward bulkhead and the MMW equipment. Allow clearances to allow opening radome. Build/procure the necessary mounts, trays, and associated connectors.

MIDCOAST: Measure, evaluate, and analyze mounting for the Honeywell MMW Antenna and RF Electronics in the G-II aircraft. Design the mounting brackets and tray(s) which will interface between the aircraft forward bulkhead and the MMW equipment. Allow clearances to allow opening radome. Build/procure the necessary mounts, trays, and associated connectors.

MIDCOAST: Design the modifications to the 19 inch equipment racks to assure their flight worthiness and seat rail mounting.

MIDCOAST: Working with GEC, design the airframe side of the HUD mounting. This includes performing the loads analysis, stress analysis, and design of any beef-ups required.

COMMENT: Due to the one-piece design of the HUD display unit, a vibration analysis is not expected to be required.

D.3.4 Equipment Installation Design

MIDCOAST: Design an intercom system that supports the requirements stated in the *Function Prototype System Performance Requirements Study*.

MIDCOAST: Establish a windshield video camera using existing STC designs or a new design as appropriate.

D.3.5 Aircraft Equipment Acquisition/Fabrication

MIDCOAST: Fabricate or acquire the equipment and parts designated by engineering or under the contract. This may include items such as wire, power inverters for additional 115vac power at both 60 Hz and 400 Hz, 19 inch equipment racks, video camera, and intercom system additions.

D.3.6 Aircraft Modification Installation

MIDCOAST: Install all equipment designated for the SIED aircraft by the engineering and acquisition tasks and contract requirements. This may include such items as 35 GHz and/or 94 GHz radomes, relocated weather radar and glideslope antenna, structural modifications and brackets, Group A wiring, power inverters, 19 inch equipment racks, intercom system, windshield camera, and connectors.

MIDCOAST: Continuity and ground fault check all wiring installed and terminated to connectors at both ends.

D.3.7 Head Up Display

MIDCOAST: Install HUD Electronics and HUD Computer Trays and terminate wiring into connectors as specified by the Master ICD. Continuity and ground fault check installed wiring for conformity to design.

MIDCOAST: Provide operational avionics bay, especially the inertial reference system. Provide assistance during final installation and boresight of the HUD Display Tray.

D.3.8 FLIR

MIDCOAST: Install brackets to house FLIR camera and its subcomponents.

D.3.9 Lear MMW Radar

MIDCOAST: Install brackets to house Lear MMW radar and its subcomponents. Physically install MMW components in radome area and cabin.

D.3.10 Honeywell MMW Radar

MIDCOAST: Install brackets to house Honeywell MMW radar and its subcomponents. Physically install MMW components in radome area and cabin.

D.3.11 Aircraft Demodifications

MIDCOAST: Remove FPSVS equipment in the least costly manner acceptable to Raleigh Jet. Return the aircraft to condition acceptable for Part 91/135 operations.

D.4 Aircraft Engineering and Modifications

MEAD: Provide engineering support in the execution of the aircraft engineering and modifications. Lead in coordinating other elements of the SIED with the subcontractor.

D.4.1 Interface Control Documents

MEAD: Establish and maintain the *FPSVS Master Interface Control Document* (Master ICD) for the SIED. Coordinate with all subcontractors to receive and approve their inputs and to assure

that the Master ICD is technically correct. Control the scope of the Master ICD and any sub-system ICD's to assure that all pertinent interfaces are managed through a single source document. The ICD will typically identify the following specifications:

1. Electrical Interfacing Requirements
2. Equipment Mounting Requirements
3. Compliance with RS-170 rastered video specifications (all devices generating or handling RS-170 video).
4. Ability of RS-170 video devices to adjust the size of the image or translate it on the display device. Controls on contrast, brightness, or other adjustments to the basic video should be detailed.
5. Environmental Requirements imposed by the mounting location(s).
6. Field of View requirements (HUD and HDD displays) as well as the capability of adjusting sensor field of view (sensors).
7. Operational Restrictions (if any) and time from turn on to full operation.
8. Power and Cooling.
9. Weight and Center of Gravity.

The Master ICD shall include the following equipment:

1. Head Up Display Subsystem
2. Head Down FPSVS Displays
3. FLIR Sensor
4. Lear Astronics MMW Sensor
5. Kodak FLIR Sensor
6. Honeywell MMW Sensor
7. Aircraft Group A Wiring. Characteristics such as wire type, connector, signal function(s), frequency or bandwidth, maximum run distance, EMI or special considerations.

D.4.2 Weather Pylon and Attachment

TBD: Design a pylon and aircraft attach points which can safely hold the JTD, Inc. weather sensors.

TBD: Fabricate Pylon and aircraft attach points for weather sensors.

D.4.3 Aircraft Demodifications

MEAD: Disposition GFE/CFE or leased equipment back to suppliers. Purchase equipment will be dispositioned as instructed by SVPO.

D.4.4 FLIR System

D.4.4.1 FLIR Window Support

MEAD: Lead in establishing design and availability of FLIR window in the radome.

MEAD: Provide engineering to assure that FLIR radome mounting that correctly positions the camera to view through the FLIR window.

D.4.4.2 FLIR Mounts and Trays

MEAD: Measure, evaluate, and analyze mounting for FLIR in the G-II aircraft. Design a mounting brackets and tray(s) which will interface between the aircraft and the FLIR camera,

cooler, and electronic units. Allow clearances to allow opening radome. Build/procure the necessary mounts, trays, and associated connectors.

D.4.5 MMW Sensor Systems

D.4.5.1 MMW Radome Support

MEAD: Lead in establishing design and availability of MMW compatible radome for both 94 and 35 GHz bands.

D.5 Norton Subcontract

NORTON: Provide attendance, support, or presentations as requested by TRW in the conduct of informal and formal reviews. These will include Technical Interchange Meetings, Preliminary and Critical Design Reviews, and Flight Readiness Reviews.

NORTON: Provide configuration management for deliverable equipment, computer codes, and documentation that is in compliance with the SIED Configuration Management Plan. Provide CM coordination to assure that current configurations being provided are in compliance with the approved flight configuration.

NORTON: Provide technical assistance in determination of design and sources for FLIR window materials. Implement FLIR window design in 35 and 94 GHz radomes for Gulfstream II airplane.

NORTON: Provide technical assistance in determination of design and sources for MMW radome materials. Implement 35 and 94 GHz radomes for the Gulfstream II airplane.

NORTON: Provide engineering assistance to assure that MMW 35 GHz and 94 GHz radomes fit to the airframe and MMW Sensor/Weather Radar/FLIR installations.

NORTON: Provide assistance on an "As Required Basis" during the Phase A flight test.

NORTON: Provide assistance on an "As Required Basis" during the Phase B flight test period.

E. Flight Operations

E.1 Operational Planning

MEAD: Lead in the development of the operational planning tasks.

E.1.1 Aircraft Experimental Operations Certificate

MEAD: Assume responsibility for technical aspects of experimental certificate application. Coordinate with Raleigh Jet in placing the application.

TBD: Develop the detail operational plans and procedures considering the following:

1. Test Site(s) Selection
2. Weather Forecasting
3. Flight/Experiment Management Methodology
4. Crew Compliment and Requirements
5. Fly/Abort Decision Criteria
6. Ground/Air Communications
7. Mission Planning Requirements
8. Crew Flight Time and Rest Requirements
9. Ferry Time Allotments
10. Approach Performed Per Flight Period
11. Logistics
12. TDY Accommodations
13. Consumables
14. Maintenance and Removal/Replacements
15. Guest Pilot/Observers Coordination and Travel
16. Test Reports, Data, Evaluations Collection

E.1.2 Operational Test Procedures

MEAD: Develop detailed criteria and techniques used to setup, perform, and document each operational task associated with a test sequence. Areas of inclusion are:

1. Identifying test run and resulting data.
2. Setup Criteria, including:
   a. Weather Requirements
   b. Aircraft Configuration
   c. SVS Operating Modes
   d. Data Recording Modes and Configuration
   e. Approach initial siting and initialization requirements
   f. Pilot briefing on task and his objectives
3. Criteria to be evaluated and assignment of evaluators (pilot, crew, or support personnel)
4. Pertinent mission rules applying to the operation that must be observed.

MEAD/Hoh: Lead in the development of the operational test procedures.

E.2 Aircraft Installation, Integration, and Test

E.2.1 System Integration and Checkout

MEAD: Lead the system final aircraft integration and checkout support effort. Prepare the time lines and details of the test efforts with the help of the respective subcontactors or vendors.

E.2.2 Weather Sensor Pylon

TBD Install weather sensor pylon and aircraft hard mounts.

E.2.3 Modifications

MEAD: Provide oversight and assistance to aircraft engineering and modification contractor.

E.2.4 Head Up Display

MEAD: Provide oversight and assistance to HUD vendor and aircraft engineering and modification contractor.

E.2.5 FLIR

MEAD: Develop a detailed installation procedure for the FLIR.

MEAD: Validate FLIR mounting provisions including mechanical interface with radome and the FLIR window in the radome.

MEAD: Perform final verification of wiring for FLIR sub-system components. Perform power and ground checks. Install FLIR subsystem and verify operation.

MEAD: Boresight FLIR to aircraft.

E.2.6 Lear MMW Radar

TBD: Boresight MMW Radar to aircraft.

E.2.7 Honeywell MMW Radar

TBD: Boresight MMW Radar to aircraft.

E.2.8 FPSVS Equipment

MEAD: Prepare a detailed installation procedure for the FPSVS equipment.

TBD: Physically install the FPSVS equipment.

MEAD: Perform final verification of wiring for FPSVS sub-system components. Perform power and ground checks. Electrically install FPSVS subsystem and verify operation.

E.3 Flight Test

E.3.1 Aircraft Sortie Planning

MEAD: The Flight Test Director shall be responsible for the planning and execution of each aircraft sortie's mission. He is to be assisted by the Flight Test Engineer.

E.3.2 Aircraft and Crew

SVPO: Identify and make available the evaluation pilots for the aircraft. Evaluation pilots selected will meet the qualification requirements established by the Pilot-In-Command for the type of operation being conducted.

MEAD: Provide a Flight Test Director who shall be responsible for the mission elements of the flight and who shall direct the specific implementation of the tests.

MEAD: Provide a Flight Test Engineer who shall be responsible for the functioning of the overall FPSVS system and the detailed operation of the data acquisition and recording equipment.

E.3.3 Shakedown Flights

MEAD: Provide the Flight Test Director and Flight Test Engineer for the execution of these flights.

MEAD: Test and verify the operation of the Data Acquisition System. Also validate the operation and correctness of the Data Reduction System (post-flight).

E.3.4 Sensor Suitability Flights

MEAD: Provide the Flight Test Director and Flight Test Engineer.

E.3.5 Phase A Flights

MEAD: Provide the Flight Test Director and Flight Test Engineer.

SPVO: Provide selected evaluation pilots and observers for the Phase A flying.

E.3.6 Phase B Flights

MEAD: Provide the Flight Test Director and Flight Test Engineer.

SPVO: Provide selected demonstration pilots and observers for the Phase B flying.

F. Technical Support

MEAD: Provide and manage experts and technical consultants needed to accomplish SIED tasks and support the SVSTD/SIED Project and CIST meetings.

F.1 Reference System Design & Program Support (Law)

MEAD/Law: Develop four Reference System Designs as a series of hypothetical, commercially viable, Synthetic Vision Systems. Each Reference System will be capable of satisfying a specific set of operational objectives that are of interest for government and/or commercial applications. These objectives are proper subsets of the more general scenarios and experiments being investigated with the functional prototype SVS.

1. Initial and principle Reference System Design shall be targeted to implement the *No Approach Nav-Aids To Lower Minimums* and the *Ground Operations In Lower Visibility* scenarios.
2. Use of SVS to achieve Category IIIa capability at Type I facilities. Include SVS extensions of ground operations capability to allow balanced landing, taxi, and takeoff conditions.
3. Use of SVS to achieve Category IIIb and/or IIIc capability, including a commensurate extension to ground operations capability.
4. Use of SVS to achieve lower minima with non-precision approach references.

Express the system design in terms of requirements. Documentation is to be layered into conceptual block diagrams, detailed diagrams showing specific subsystem or architectural requirements, data or process flow diagrams as required, and written descriptions which describe and enhance the graphical data.

Propose specific design approaches to the solution of technical issues and, where possible, also describe alternative solutions. Design documentation will remain at the requirement level so as not to preclude any specific sensors, display, or processing system. Provide a plausible operational environment for the synthetic vision capability including ground support, air traffic control, and operational rules.

MEAD/Law: Provide technical support and expertise in development or resolution of specific issues and/or tasks as directed by the SIED Program Office.

F.2 Technical Exchange & Program Support (Hoh)

MEAD/Hoh: Perform the duties of the joint government/industry Synthetic Vision Certification Issues Study Team (CIST) Secretariat. Assume responsibility for CIST organization, facilitation, scheduling, and comprehensive meeting summary. Distill, extract, and refine CIST data or reports for final publication or release. The facilitation task includes the distillation of significant concepts and issues resulting from the efforts of the team and its subelements.

MEAD/Hoh: Provide technical support and expertise in development or resolution of specific issues and/or tasks as directed by the SIED Program Office.

F.3 SVSTD/CIST Expert Technical Assistance (Hayes)

Hayes: Support CIST meetings, Tower Testing, and SVSTD/SIED Development.

F.4 CIST/SVPO Imaging Evaluation Assistance (Mengers)

Mengers: Support CIST meetings and SVPO evaluation of imaging enhancement and evaluation techniques used in tower and flight sensor configurations.

F.5 Boston Harbor Vessel Detection (Hayes)

Hayes: Support the Boston Harbor Vessel Detection task.

Appendix B - WBS RESOURCES

2/1/93	D. O. 17 RESOURCE ALLOCATION PLAN								
FN:DECRESS			MEAD GPWA						
FAC BASED ON NOVRES3 USED FOR DEC CSSR /PLUS GPWA REV. 4 AND ADJUSTMENTS							UNDER/	RATE	BOOKING
			PRELIMINARY		JAN FAC	DEC FAC	OVER	DELTA	FAC
	ITD DEC 92	1991-1992			1991-1993	1991-1993			1991-1993
WBS	ACWP	TOTAL	JAN 93	Feb-93	TOTAL	TOTAL			TOTAL
SVTD/OE MGMT - A									
PROG MGMT	906,792	906,792	39,466	34,200	980,458	946,258	-34,200	49,203	1,029,661
TRAVEL/ODC	187,922	187,922	12,373	6,000	206,295	199,911	-6,384		206,295
CONFIG MGMT	36,052	36,052	5,302	3,000	44,354	45,174	820	3,218	47,572
S/C MGMT	211,855	211,855	6,000	7,000	224,855	215,347	-9,508	17,339	242,194
PROG REVIEWS	82,569	82,569	0		82,569	82,569	0	10,403	92,972
DATA ITEMS	287	287	5,367	4,000	9,654	8,162	-1,492		9,654
COST/BENEFIT	0	0	0		0	0	0		0
START-UP JN	257,880	257,880	0		257,880	257,880	0	32,384	290,264
TOTAL MGMT-A	1,683,357	1,683,357	68,508	54,200	1,806,065	1,755,301	-50,764	112,547	1,918,612
SYS/ANAL STUDIES - B									
OPER SCEN/EXP	13,795	13,795	0		13,795	13,795	0	1,768	15,563
DATA ACQ/RED	4,309	4,309	0		4,309	4,309	0	539	4,848
DATA/ ANAL/DOC	81,203	81,203	9,965		91,168	91,168	0	0	91,168
FINAL REPORT	10,042	10,042	28,000	35,000	73,042	58,367	-14,675	0	73,042
GTRI S/C	220,000	220,000	43,492	5,000	268,492	263,492	-5,000		268,492
JTD S/C	113,351	113,351	2,800		116,151	116,151	0		116,151
SIM STUDIES	113,485	113,485	0		113,485	113,416	-69	12,998	126,483
SIM S/C	167,547	167,547	0		167,547	167,547	0		167,547
EXPER/SCEN DEFIN	1,401	1,401	0		1,401	1,401	0	0	1,401
PLAN/SCHED	13,546	13,546	0		13,546	13,547	1	1,627	15,173
TOTAL SYS ANAL-B	738,679	738,679	84,257	40,000	862,936	843,193	-19,743	16,932	879,868
FUNCT P/T SYS DESIGN - C									
REQMTS/SE/SPECS	111,663	111,663	0		111,663	111,663	0	14,288	125,951
HARDWARE DESIGN	100,028	100,028	0		100,028	100,028	0	12,246	112,274
SOFTWARE DESIGN	65,679	65,679	0		65,679	65,675	-4	7,919	73,598
MECHANICAL DESIGN	72,248	72,248	0		72,248	72,067	-181	3,952	76,200
IMPL & INTEG	171,364	171,364	136		171,500	171,500	0	13,624	185,124
HOT BENCH I&T	129,400	129,400	0		129,400	128,717	-683	0	129,400
LEAR S/C	133,047	133,047	0		133,047	133,047	0		133,047
GEC S/C	175,738	175,738	58,220		233,958	233,958	0		233,958
KODAK S/C	14,547	14,547	0		14,547	14,547	0		14,547
TOTAL SYS DES-C	973,714	973,714	58,356	0	1,032,070	1,031,202	-868	52,029	1,084,099
NOTE:	PROGRAM MGMT ACTUALS INCLUDE LEAR PROPOSAL COSTS PER MTSP								
	HOT BENCH I&T-LABOR TRANSFER TO A/C INSTALL & I&T IN OCT 92								
	GEC-$9119 OF MATL TRANSFERRED FROM GEC ACTUALS TO IMPL & INTEG IN SEP 92								

2/1/93	SYNTHETIC VISION SYSTEM								
FN:DECRESS			PRELIMINARY						
FAC BASED ON NOVRES3 USED FOR DEC CSSR /PLUS GPWA REV. 4 AND ADJUSTMENTS							UNDER/	RATE	BOOKING
8					JAN FAC	DEC FAC	OVER	DELTA	FAC
	ITD DEC 92	TOTAL	JAN 93		1991-1993	1991-1993			1991-1993
WBS	ACWP				TOTAL	TOTAL			TOTAL
AIRCRAFT PREPARATION - D									
A/C SPECS AND ACQ	26,203	26,203	0		26,203	26,294	91	985	27,188
RALEIGH JET A/C	1,388,916	1,388,916	7,000		1,395,916	1,383,421	-12,495		1,395,916
A/C MODIFICATION S/C	586,775	586,775	0		586,775	586,774	-1		586,775
AIRCRAFT ENG & MODS	209,242	209,242	0		209,242	209,214	-28	24,867	234,109
NORTON S/C	87,884	87,884	0		87,884	87,884	0		87,884
TOTAL AIRCRAFT PREP-D	2,299,020	2,299,020	7,000	0	2,306,020	2,293,587	-12,433	25,852	2,331,872
FLIGHT OPERATIONS - E									
OPERATIONAL PLANNING	14,907	14,907	0		14,907	14,907	0	1,899	16,806
A/C INSTALL & I&T	164,833	164,833	0		164,833	164,715	-118	83	164,916
FLIGHT TEST	131,773	131,773	0		131,773	121,499	-10,274	0	131,773
TOTAL FLIGHT OPS-E	311,513	311,513	0	0	311,513	301,121	-10,392	1,982	313,495
TECHNICAL SUPPORT - F									
PREP SYS DESIGN/LAW	216,944	216,944	14,391	10,000	241,335	231,335	-10,000		241,335
TECH EXCHANGE SPT/HOH	232,268	232,268	17,267	18,000	267,535	249,535	-18,000		267,535
TECH ASSISTANCE/HAYES	40,811	40,811	10,895		51,706	51,706	0		51,706
TECH ASSISTANCE/MENGERS	37,925	37,925	2,998		40,923	40,923	0		40,923
BOSTON HARBOR/HAYES	44,856	44,856	961		45,817	45,817	0		45,817
TOTAL TECH SUPPORT-F	572,804	572,804	46,512	28,000	647,116	619,116	-28,000	0	647,116
TOTAL WBS	6,578,887	6,578,887	264,633	122,200	6,965,720	6,843,520	-122,200	209,342	7,175,062
TOTAL CUM WBS	6,578,887								0
									0
EST ICOM	164,254	164,254	949	1,000	166,203	165,203	-1,000		166,203
FEE									
TOTAL D. O. 17	6,743,141	6,743,141	265,582	123,200	7,131,923	7,008,723	-123,200	209,342	7,341,265

Appendix C - CDRL DOCUMENT OUTLINES

This section provides outlines of selected CDRL documentation. As final documents are released and approved, these references will be updated to reflect the final form. The CDRL documents are listed below.

A001 - Task Accomplishment Plan / Program Plan‡

X008 - Functional Prototype System Performance Requirements Study

X009 - Configuration Control Plan‡

X011 - Development Design Drawings and Associated Lists‡

X010 - Design Issues and Deficiencies Report‡

X006 - Simulation Plans

X007 - Simulation Results

X002 - Flight Safety Plan

X012 - Flight Test Plans

X013 - MMW Sensor Data Collection Summary

X014 - Functional Prototype System Flight Test Data Summary

A007 - MMW Sensor Data Collection Flight Results & Analysis

A007 - Functional Prototype System Flight Test Results

X004 - Reference System Design

A005 - Final Report

‡ These documents will not be outlined.

1. Functional Prototype System Performance Requirements Study

Introduction
Imaging Sensor Performance
- Lear MmW
- Honeywell MmW
- Kodak FLIR
- TV

Functional Prototype SVS
- Symbol Generator
- Cockpit Head Up Display
- Cockpit Head Down Display
- Work Stations
  - Test Director
  - Test Engineer
  - Observer
- Interface Unit

Data Acquisition System
- Imaging Sensor(s) Data
- Aircraft Data
- Weather Data

Hot Bench
Aircraft
- Nose/Radome Mounting
- Radome Characteristics
- Cockpit
  - HUD Provision
  - HDD Provision
  - Controls
- Cabin Provisions
- Weather Pylon

Aircraft Ground Operations Requirements
- Power Cart/APU
- Engines

Aircraft Operational Requirements
- Ferry
- Approaches
  - Full Stop
  - Touch and Go
  - Low Approach

Simulation
- Facility Requirements
- Operational Requirements

Data Analysis
- Simulation Results
- MmW Sensor Performance
- FPSVS Performance
- Experiments
- Operational Scenarios

APPENDIX A - SVTD/ATSVS Goals and Objectives
APPENDIX B - Operational Scenarios and Experiments
APPENDIX C - Issues, Criterion, Rationale
APPENDIX D - Independent Flight Conditions
APPENDIX E - Analysis Requirements
APPENDIX F - Data Elements and Sources

2. Flight Test Plans

Introduction
Test Site Selection/Qualification
- Test Condition Compliance
- Environment and Geometery
- Test Support Installations
- Nav-Aid Requirements

Flight Planning
- Weather Forecasting
- Ferry Time
- Local Flights
- TDY Deployments
- Go/No-Go Criteria
- Crew Requirements
- Support Requirements

Coordination And Approvals
- Experimental Authorization
- ATC Authorization/Coordination
- Facility Authorization/Coordination
- FCC Frequency Allocation Authorization for MMW Transmitter(s)

Logistics
- Consumables
- Maintenance Removals/Replacements
- Guest Pilots & Observers
- Data and Reports

Air Crew Requirements
- Qualifications
- Training
- Minimum Crew

Flight Operations
- Communication Discipline
- Resource Management Discipline
- Crew Station (Normal) Procedures
- Below Minima (Normal) Procedures
- Emergency Procedures

Mission Rules
Flight Readiness Review Requirements
- Shakedown
- Suitability
- Phase A
- Phase B

APPENDIX A - Flight Test Methodlology
APPENDIX B - Flight Test Matrix
APPENDIX C - Flight Test Traffic Model
APPENDIX D - Aircraft Flight Manual Supplement
APPENDIX E - Shakedown Test Procedures
APPENDIX F - Suitability Test Procedures
APPENDIX G - Phase A Test Procedures
APPENDIX H - Phase B Test Procedures

3. Safety Plan

- Introduction
- Safety Review/Approval Process
  - Independent Review Board
    - Membership
    - Authority
  - Flight Readiness Review
  - Phase A Flight Review
  - Below Minimum Approval
  - Phase B Flight Review
- SVTD/ATSVS Hazard Analysis
  - Mechanical
    - Weather Pylon
    - MmW Radome(s)
    - MmW Installation
    - FLIR Installation
    - Cockpit Modifications
    - Cabin Modificaitons
  - Electrical
    - EMI
    - EMC
    - MmW Sensor(s)
    - FLIR
    - TV
    - FPSVS
      - HUD Symbol Generator
      - HUD Display
      - HDD Display
      - Interface Unit
      - Test Engineer Console
    - EFIS (Modified)
    - Power Busses
    - Intercoms
  - Crew
    - Two-Man Workload
    - Pilot Disability
    - Guest Pilots
    - Test Crew/Observers
    - Command/Resource Management
  - Operations Below Existing Minima
    - Reliability Considerations
    - Go Around
  - Hard Landing
- Aircraft Modification Loads and Stress Report(s)
- FPSVS Rationale For FMEA and Reliability Analysis Waiver
- Safety Requirements
  - Architectural
  - Mechanical
  - Avionics
  - Software V&V
  - Training
  - Operational Rules and Restrictions
  - Mission Rules

4. Final Report

- Introduction
    - SVTD Project
        - Goals, History, Other Activities
    - SIED Purpose
    - SIED Scope
    - Applicable Documents
- Executive Summary
    - Goals, Objectives, Methods
    - Achievements
    - Conclusions and Recommendations
- Goals and Objectives
    - Scenarios
    - Experiments
- Methods
    - Simulation
    - Functional Prototype SVS
- Achivements
    - Simulation
    - In-Flight Evaluation
- Conclusions
    - Operational Performance Of Functional Prototype Synthetic Vision System
        - Operational Issues Resolution
        - Operational Scenarios
            - Extend ILS To Lower Minimums
            - Extend Non-Precision Approaches To Lower Minimums
            - Allow No-Apporach-Nav-Aid Approaches To Lower Minimums
            - Ground Operations In Very Low Visibility
        - Environment and Weather Effects
        - MMW Sensor
        - FLIR Sensor
    - *Runway Intrusion* Protection
    - *Image Quality* Assessment
    - Technology Limitiations
- Recommendations
    - Human Factors
    - Sensor Systems
    - Display Systems
    - System Integration
    - Aircraft Integration
    - Experimental/Test Methodology
    - Reference System Design
    - Micro-Electronic Technology Development
- Appendix A - Experimental Design
- Appendix B - Operational Planning
- Appendix C - Aircraft Modifications
- Appendix D - Functional Prototype Synthetic Vision System
- Appendix E - Test Operations
- Appendix F - Data Reduction/Analysis Tools
- Appendix G - Test Data Results
- Appendix H - Index To Test Data
    - System Data
    - Video Data

SVSTD/SIED PROGRAM PLAN - VOLUME II

EXPERIMENTAL DESIGN

Contract F04606-90-D-0001/0017

SOW SM-ALC/TIE 91-308

Synthetic Vision System Technology Demonstration Project

System Integration, Evaluation, Demonstration Task

Document No. D1-6010

Version 1.0 Dated February 10, 1992

APPROVED:

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CONCURRENCY:

Honeywell	Raleigh Jet Enterprises
GEC Avionics	Midcoast Aviation
Georgia Tech Research Institute	Norton Company
JTD	Kodak

REVIEW AND COMMENT:

Lear Astronics	Malibu

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CONTENTS

LIST OF FIGURES

1. INTRODUCTION

1.1 Purpose

Volume II of the SVSTD/SIED Program Plan documents the experimental design used in the System Integration, Evaluation, and Demonstration (SIED) task of the FAA/Government's Synthetic Vision Technology Demonstration Project:

- The SIED experimental goals and objectives are documented.
- Operational scenarios for the investigations are defined.
- Specific issues determining Synthetic Vision technology's success in achieving the operational scenarios are identified and documented.
  - Scope and criterion for evaluation of each issue is given along with the supporting rationale.
  - Necessary test conditions for each issue are identified.
  - Specific measures of performance are identified.
  - Report formats for analysis results are proposed.
  - Required data elements to support the analysis are determined.
  - The underlying data sources are defined.
  - Priorities are established to guide flight test planning.
- Experiments characterizing the capabilities of the synthetic vision sensors are described.
  - Purpose of the experiment is described.
  - Methedology used in performing the experiment is given.
  - Reporting formats for the results are proposed.
- Efforts made to assure that SIED task data will form a consistent data set with other tasks being performed by the FAA/Government SVSTD Project are reviewed.

1.2 Scope

Volume II addresses only the experimental design for the SVSTD/SIED. Other areas (i.e. safety, host airport limitations, operational considerations, etc) are integrated with the experimental design in the Test Plan and summarized in Volume I. Figure 1-1 illustrates the scope of the experimental design and its relationship to the overall SIED flight evaluation task.

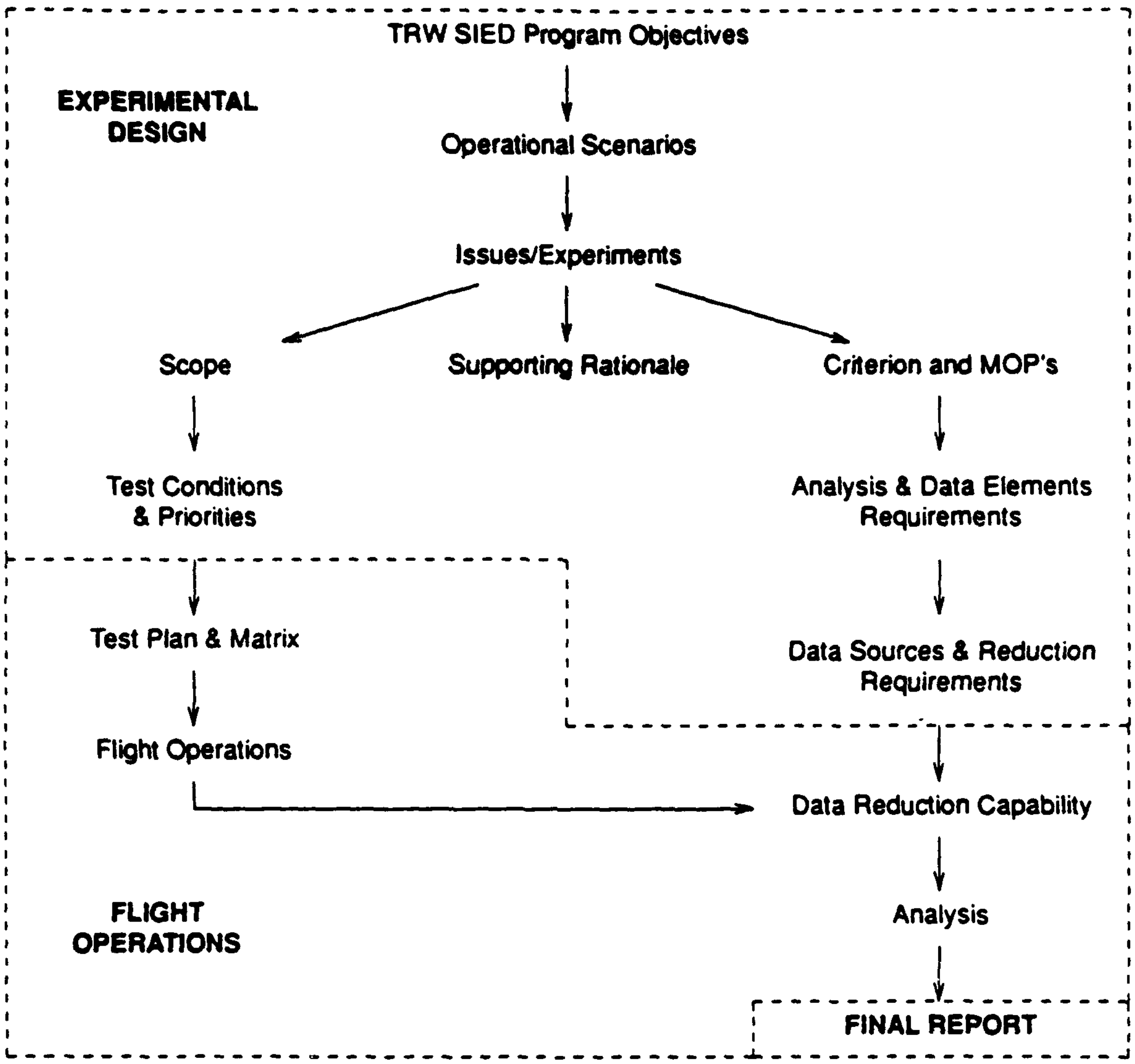


Figure 1-1. Experimental Design Scope And Integration

1.3 Applicable Documents

Refer to SVSTD/SIED Program Plan - Volume I for the list of applicable documents.

1.4 Updates

SVSTD/SIED Program Plan - Volume II will be updated as required to maintain congruence with the Experimental Design. This update may or may not be concurrent with the updating of other Program Plan volumes. The current revision levels for all portions of the Program Plan are provided in the monthly *Status Report* (CDRL Sequence No. X003).

2. EXPERIMENTAL DESIGN OBJECTIVES

The experimental design is intended to satisfy a subset of the overall SVSTD/SIED Program Goals and Objectives.[1] The flowdown to the experimental deisgn objectives is shown in Figure 2-1 below:

TRW SIED PROGRAM GOAL
Implement, demonstrate, and document the capabilities of current synthetic vision system technology to achieve safe aircraft landing, takeoff, and ground operations in very low visibility conditions.

↓

TRW SIED PROGRAM OBJECTIVES
Establish a technology benchmark through comprehensive documentation of actual system performance achieved in low visibility flight tests with a completely functional, prototype Synthetic Vision System.

↓

EXPERIMENTAL DESIGN OBJECTIVES

A. Emperically measure' the achieved performance of the integrated pilot / synthetic vision system during low visibility operations.

B. Assess the pilot's capabilities and workload when using the functional prototype synthetic vision system in low visibility operations.

C. Determine the operational characteristics of the imaging sensors used in the functional prototype synthetic vision system in terms of the airport environment and actual weather encountered.

1. Physical phenomena of millimeter wavelength radar imaging of airport scenes at low grazing angles.
2. Performance of the millimeter wavelength radar and its image processing under operational conditions.
3. Performance of the forward looking infra-red sensor under operational conditions.

D. Determine, document, and correlate the actual weather conditions existing between the aircraft and the runway for all investigations.

E. Determine image quality in a manner that can be correlated to achieved perfomance and is transferable to generic synthetic vision systems.

Figure 2-1. Flow Down Of Experimental Design Objectives

1. SVSTD/SIED Program Plan - Volume I fully describes the TRW SIED Program Goals and Objectives.

3. OPERATIONAL SCENARIOS

The experimental design objectives call for measurement of achieved performance and assessment of pilot capabilities while using synthetic vision to extend low visibility operations in the terminal environment. This section defines the operational scenarios that will be used in achieving those experimental design objectives. The applicable assumptions and conditions are given along with a recommended success criterion for their evaluation.

3.1 Terminal Operations And Tasks

Figure 3-1 shows a profile view of terminal operations which is helpful in understanding the scenarios. Typical segments of approaches have been delineated vertically and the primary tasks required of the pilot during each segment listed. Across the top of figure, different approach types are shown at the point where the pilot must start using the synthetic vision capability.

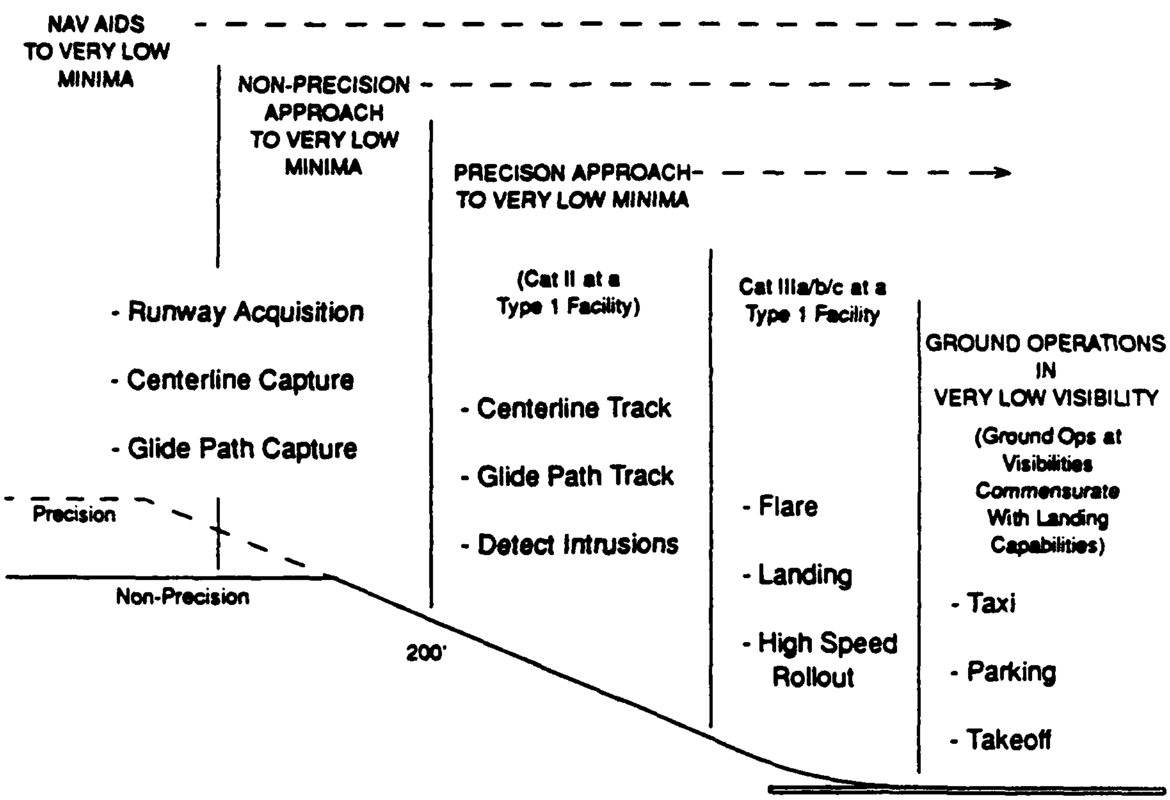


Figure 3-1. Terminal Operations Tasks

3.2 Scenario A: Precision Approach To Lower Minima

A synthetic vision system is used to support manually flown precision approaches which may continue through the end of rollout in very low visibility conditions.

3.2.1 Assumptions and Conditions:

1. Aircraft is utilizing a charted precision approach at a Type I facility and is cleared to Category I minima[2] without the use of synthetic vision.

---

2. Category I minima is nominally 200 feet agl decision height and 2400 RVR.

2. The aircraft has previously intercepted and is now tracking the precision nav-aid's course guidance signal.
3. The aircraft has previously intercepted and is now tracking the precision nav-aid's glideslope signal.
4. Aircraft has already been configured for landing.
5. The desired lower minima using the synthetic vision system includes the following:
    1. Category II nominal minima (100' agl ceiling and 1200 RVR).
    2. Category IIIa nominal minima (50'agl ceiling and 700 RVR).
    3. Continue through end of rollout in very low visibility.

3.2.2 Success Criterion:

The precision approach requires that the pilot be able to successfully complete the requirements of the following detailed operational issues (described in Section 4) in a fully integrated manner.

- Runway Centerline Track
- Glide Path Track
- Flare And Touchdown Maneuver (approaches below Category II minima)
- Lateral Landing Maneuver (approaches below Category II minima)

3.3 Scenario B: Non-Precision Approach To Lower Minima

A synthetic vision system is used to support manually flown non-precision approaches which may continue through the end of rollout in very low visibility conditions.

3.3.1 Assumptions and Conditions:

1. Aircraft is operating on a published non-precision approach and is cleared to descend to the MDA/MAP without the use of synthetic vision.
2. The approach design and navigation capability of the aircraft is capable of placing the aircraft on a straight-in course that is within 6° of the runway heading and overlays or intercepts the runway centerline at or near the approach end of the runway.
3. The runway construction and markings are suitable for a "Non-Precision Instrument Runway" or better.
4. A visual descent point (VDP) is charted for the approach. This is the point at which a "normal" descent to the runway may be started. The VDP also implies that the "normal" descent has been surveyed to be free of obstructions, obviating the need for airborne detection of obstacles along the approach path.
5. The aircraft is flying at the charted Minimum Descent Altitude (MDA) as it approaches the VDP.
6. The aircraft is configured for landing.

3.3.2 Success Criterion:

The non-precision approach requires that the pilot be able to successfully complete the requirements of the following detailed operational issues (described in Section 4) in a fully integrated manner.

- Airport Detection And Confirmation
- Runway Detection
- Runway Centerline Capture
- Runway Centerline Track
- Glide Path Capture
- Glide Path Track
- Flare And Touchdown Maneuver (approaches below Category II minima)
- Lateral Landing Maneuver (approaches below Category II minima)

3.4 Scenario C: No Approach Nav-Aids To Below Minimum Altitudes Prescribed For IFR Operations[3]

A synthetic vision system is used to support maunaully flown, enroute or off-airway approaches which may continue through the end of rollout in very low visibilities.

3.4.1 Assumptions and Conditions:

1. The aircraft is operating in the enroute or off-airways environment and is in compliance with FAR 91.175(i)[4] and 91.177(a)(2)[5].
2. The approach design and navigation capability of the aircraft is capable of placing the aircraft on a straight-in course that is within 6° of the runway heading and overlays or intercepts the runway centerline at or near the approach end of the runway.
3. The runway construction and markings are suitable for a "Visual Runway" or better.
4. The aircraft is configured for landing.
5. The aircrft is flying level at the Minimum Safe Altitude prescribed for IFR operations.
6. Before descending below the applicable minimum safe altitude prescribed for IFR operations, the synthetic vision system must allow the pilot to comply with the requirements of FAR 91.175(c)[6].
7. Obstacle clearance below the applicable minimum altitude prescribed for IFR operations is the responsibility of the pilot.

3.4.2 Success Criterion:

The no approach aids scenario requires that the pilot be able to successfully complete the requirements of the following detailed operational issues (described in Section 4) in a fully integrated manner. Notice that this list is exactly the same as that for Non-Precision Approaches.

- Airport Detection And Confirmation
- Runway Detection

3. Generally the MEA or MOCA (within 22 nmi of VOR) on-airways; 1000 (2000 in mountainous areas) feet above obstacles within 4 nmi of selected course when operating off-airways.
4. Takeoff and landing under IFR (Operations on unpublished routes and use of radar in instrument approach procedures).
5. Minimum altitudes for IFR operations (Operation of aircraft at minimum altitudes. / If no applicable minimum altitude is prescribed...)
6. Takeoff and landing under IFR. (Operation below DH or MDA).

- Runway Centerline Capture
- Runway Centerline Track
- Glide Path Capture
- Glide Path Track
- Flare And Touchdown Maneuver (approaches below Category II minima)
- Lateral Landing Maneuver (approaches below Category II minima)

3.5 Scenario D: Ground Operations In Lower Visibility

A synthetic vision system is used to support ground operations in very low visibilities.

3.5.1 Assumptions And Conditions:

1. The aircraft is assumed to have weight on all landing gear, rudder and/or nose-wheel steering control active, and to be operating under its own power.

3.5.2 Success Criterion:

Ground Operations requires that the pilot be able to successfully complete the requirements of the following detailed operational issues (described in Section 4) in a fully integrated manner.

- High Speed Rollout
- Ground Operations
- Takeoff Maneuver

3.6 Non-Precision *versus* No-Approach-Nav-Aid Scenarios

Review of Scenarios B and C above show that the only substantial difference involves how the approach is initiated. The MMW sensors available to the TRW SIED Program are not designed for operation beyond 5 kilometers of slant range. This effectively limits maximum altitudes to roughly 800 feet with the required 3° glide path angle. At these low altitudes there are no differences between the two scenarios and they will be treated as one in the development of the test plan and matrices.

3.7 Task Redundancies

Review of the success criterion for the above scenarios shows that there are a number of piloting tasks that must be performed successfully while using the functional prototype synthetic vision system. Most of these pilot tasks repeat between the various scenarios, allowing their exploitation in optimizing the test matrices and in improving the confidence of the test results. Figure 3-2 summarizes the task redundancies between the in-flight scenarios:

TASK REDUNDANCIES ACROSS SVS FLIGHT SCENARIOS			
Pilot Task	Scenario		
	Precision	Non-Precision	No Approach Aids
Airport Detection & Confirmation	No	Yes	Yes
Runway Detection & Confirmation	Yes	Yes	Yes
Runway Centerline Capture	No	Yes	Yes
Runway Centerline Track	Yes	Yes	Yes
Glide Path Capture	No	Yes	Yes
Glide Path Track	Yes	Yes	Yes
Flare Maneuver	Yes	Yes	Yes
Landing Maneuver	Yes	Yes	Yes
High Speed Rollout	Yes	Yes	Yes
Taxi	Yes	Yes	Yes

Figure 3-2. Task Redundancies Across SVS Flight Scenarios

4. OPERATIONAL PERFORMANCE ASSESSMENT

Working within the boundries of the operational scenarios, this section documents the issues that must be investigated to establish the operational portion of the synthetic vision technology benchmark while remaining within the available resources of the TRW SIED Program.

4.1 Operational Performance Issues

Each of the piloting tasks associated with the operational scenarios has been selected as an *Issue*. This section defines the methodology, conditions, and analysis that will be utilized to determine the results of the issue investigations. This approach enables the subjective pilot evaluations of those flying tasks to be directly substantiated by the quantative performance measurements.

Each *Issue* presented is documented in the following terms:

A. ISSUE - A statement of the question to be resolved.

B. SCOPE - The range of conditions and environments over which the issue must be evaluated and the tasks which determine the issue result. The scope will contain the following elements:

   1. Description - statement of what is to be accomplished.

   2. Initial Conditions - items which must be accomplished or satisfied before the measured issue can start.

   3. Test Conditions - those items which will be controlled during the testing to present the system with specific situations. The priorities and values assigned to each of these test conditions are detailed in Section 4.2.

   4. Tasks - the specific functions or procedures which the pilot must accomplish.

C. CRITERION - Expectation which should allow the the issue to be resolved. The elements of the criterion include:

   1. Measure of Performance - the item(s) which are to be measured. Since the TRW SIED Program objectives are to establish a technolgoy benchmark, the specification of acceptable values for each MOP will not be made. Similarly, no required level of confidence for the data is stated.

   2. Report Parameters - those parameters which will be used to document the results in the final report. Section 4.3 summarizes the parameters and explains their planned final report presentation format.

   3. Data Elements - the measurements that are required to generate the report paramters.

   4. Data Sources - the physical sensors that will make, format, and transmit the measurements to the data acquisition system.

D. RATIONALE - Justifies why the an issue is sufficiently relevant to be included. Explains the reason for the choice of MOP values, report paramters, and data element/source requirements.

4.2 Airport Detection And Confirmation

Can a pilot detect the airport while using the functional prototype synthetic vision system?

4.2.1 Scope:

4.2.1.1 Description: On non-precision approaches, the pilot must locate and identify the airport the synthetic vision display with a reasonable degree of confidence.

4.2.1.2 Initial Conditions: Aircraft may be in either level flight at, or in a descent to the Glide Path Intercept Altitude (nominally the MDA). The aircraft's course is established by use of an enroute or non-precision approach navigation aid or ATC vectors and is nominally aligned so that it will intersect the airport's usable landing surface. Distance to the airport is greater than the range of the imaging sensor or 10 miles, whichever is less.

4.2.1.3 Test Condition 1: Weather Conditions

4.2.1.4 Test Condition 2: Airport Surfaces

4.2.1.5 Test Condition 3: Imaging Sensor

4.2.1.6 Test Condition 4: Glide Path Intercept Altitude

4.2.1.7 Test Condition 5: Approach Offset Angle

4.2.1.8 Test Condition 6: Display Used

4.2.1.9 Test Condition 7: Day/Night

4.2.1.10 Task 1: Pilot maintains course and altitude using standard IFR procedures, instruments, and navigation aids. At the option of the pilot, a bracketing maneuver may be used to expand the field of regard of the SVS system while searching for the airport.

4.2.1.11 Task 2: Pilot interprets the SVS image on HUD and HDD displays and verbally declares that the airport has been detected when he is reasonably sure that he has sighted it on the SVS.

4.2.1.12 Task 3: Pilot continues attempts to confirm the airport by any combination of reinforcing factors available on the SVS or cockpit/SVS symbology such as significant landmarks, pattern of layout, or position estimates of accepted IFR navigational aids. The Pilot verbally declares any loss of confidence in the identification of the airport or detection of an error.

4.2.2 Criterion:

4.2.2.1 MOP 1: Detection of the airport must be accomplished prior to reaching either a point from which a normal descent to the approach end of the runway cannot be made, or the published/planned terminating point for the IFR operation being conducted.

4.2.2.2 Report Content:

A. Pilot evaluation of capability.

B. Airport detection event shown on plan view of aircraft track with respect to runway.

C. Correlation between sighting range and the weather conditions existing between runway threshold and the aircraft.

4.2.2.3 Data Elements:

A. Pilot Commentary concerning airport detection task.

B. Aircraft position history with respect to the desired runway.

C. Event marker in data acquisition stream identifying airport detection.

D. Weather conditions existing between aircraft and runway at the time of detection.

4.2.2.4 Data Sources:

A. Subjective pilot opinion on commentary sheet and debrief.

B. INS, GPS, or mixed navigation sensors (position)

C. Airport Event Marker - Discrete recorded in the data stream to indicate when pilot declared airport detection.

D. Direct measurement total water content and particle size distribution sensors.

E. Airport site survey data.

4.2.3 Rationale:

Flight under visual conditions generally results in the airport area being detected prior to the desired runway. This may not be true when using the functional prototype synthetic vision system due to its sensor characteristics combined with the requirement for straight-in approachs which place the runway touchdown zone significantly closer to the aircraft than the general airport area.

The detection of the airport on non-precision approaches may remain as a significant event in the process of assuring that a descent below minimum safe altitude is not made towards a non-runway.

A correlation to image quality is not made for airport detection since there is no guarantee of a scene content reference standard. It is made for runway detection (Section 4.1.2).

4.3 Runway Detection

Can a pilot detect and confirm the desired runway while using the functional prototype synthetic vision system?

4.3.1 Scope:

4.3.1.1 Description: The pilot must determine that the desired runway has been sighted in the synthetic vision display to a reasonable degree of confidence. He must then reinforce that level of confidence to a very high level before descending below the minimum safe altitude for the instrument operation being performed. This effort must consider off-airport features that resemble runways as well as on-airport taxiways and parallel runways.

4.3.1.2 Initial Conditions: The aircraft is established in the landing configuration on a straight-in (±5°) approach to the desired runway. Aircraft may be in either level flight or in an approach descent to the Glide Path Intercept Altitude (nominally MDA). Distance to the airport is greater than the range of the imaging sensor or 10 miles, whichever is less. Airport Detection And Confirmation may or may not be completed.

4.3.1.3 Test Condition 1: Weather Conditions

4.3.1.4 Test Condition 2: Airport Surfaces

4.3.1.5 Test Condition 3: Imaging Sensor

4.3.1.6 Test Condition 4: Glide Path Intercept Altitude

4.3.1.7 Test Condition 5: Approach Offset Angle

4.3.1.8 Test Condition 6: Display Used

4.3.1.9 Test Condition 7: Day/Night

4.3.1.10 Task 1: Pilot maintains course and altitude using standard IFR procedures, instruments, and navigation aids. At the option of the pilot, a bracketing maneuver may be used to expand the field of regard of the SVS system while searching for the runway..

4.3.1.11 Task 2: Pilot interprets the SVS image on HUD and/or HDD displays and verbally declares that the runway has been detected when he is reasonably sure that he has sighted it on the SVS.

4.3.1.12 Task 3: Pilot continues attempts to confirm the runway by any combination of reinforcing factors available on the SVS or cockpit/SVS symbology such as significant landmarks, pattern of layout, or position estimates of accepted IFR navigational aids. The Pilot verbally declares any loss of confidence in the identification of the runway or detection of an error.

4.3.1.13 Task 4: The evaluation pilot or the safety pilot will verbally declare when out-the-window visual contact is made with the runway or its environment as defined in FAR 91.175(c)(3)(ii - x).[7]

4.3.2 Criterion:

4.3.2.1 MOP 1: Detection of the runway must be accomplished prior to reaching either a range from which a normal descent to the approach end of the runway cannot be made, or the published/planned terminating point for the IFR operation being conducted.

4.3.2.2 MOP 2: The range difference between runway detection by SVS and normal vision for the given weather and sensor combination.

7. Takeoff and landing under IFR (Operation below DH or MDA/Visual References)

4.3.2.3 Report Content:

1. Pilot evaluation of capability.
2. Point of runway detection while using SVS shown on plan view of trajectory.
3. Point of runway detection while using normal vision shown on plan view of trajectory.
4. Performance correlation with weather conditions.
5. Performance correlation with image quality.
6. Assessment of raw radar data content at range of detection while using the MMW Radar as the primary sensor in the functional prototype SVS (on selected runs only).

4.3.2.4 Data Elements:

A. Pilot commentary on runway detection task.

B. Aircraft position at time of SVS runway detection.

C. Aircraft position at time of visual runway detection.

D. Video data representing the functional prototype SVS image that pilot was able to see on HUD.

E. Video data representing the functional prototype SVS image on HDD.

F. MMW radar data at time of runway detection (on selected approaches).

4.3.2.5 Data Sources:

A. Subjective pilot opinion on commentary sheet and debrief.

B. INS, GPS, or mixed navigation sensors (position).

C. SVS Runway Event Marker - Discrete recorded in the data stream to indicate when pilot declared runway detection.

D. Visual Runway Event Marker - Discrete recorded in the data stream to indicate when runway was visually detected by either pilot.

E. HUD Camera RS-170 video data.

F. Radar RS-170 video data.

G. FLIR RS-170 video data.

H. MMW Radar Raw Image (on selected approaches).

I. Direct measurement total water content and particle size distribution sensors.

J. Airport site survey data.

4.3.3 Rationale:

Detection of the runway and/or its immediate environment is a regulatory prerequisite for descent below existing IFR minima. This makes the characterization of the pilot's ability to detect it while using the functional prototype SVS very important. Additionally, the capability of the HUD enhanced synthetic vision system to capture and track both centerline and glide path is based on being able to see a substantial portion of the runway.

The point at which the pilot declares the runway detected will be used as a reference point for a number of experiments involving image quality, runway size in pixels, and the characterization of radar processing performance (on selected runs).

The difference between the functional prototype SVS detection and normal vision detection provides a first approximation of the relative capability of synthetic vision sensors.

4.4 Runway Centerline Capture

Can the pilot maneuver the aircraft to intercept and capture the desired runway's centerline while using the functional prototype synthetic vision system on non-precision approaches?

4.4.1 Scope:

4.4.1.1 Description: When flying on a non-precision approach the pilot must determine the location of the runway centerline extension relative to the aircraft and then maneuver to intercept the centerline extension at a distance from the runway threshold suitable for continuing the approach.

4.4.1.2 Initial Conditions: The aircraft is established in the landing configuration on a straight-in (±6°) approach to the desired runway. Aircraft may be in either level flight or descending to the MDA. Runway Detection has been completed.

4.4.1.3 Test Condition 1: Weather Conditions

4.4.1.4 Test Condition 2: Airport Surfaces

4.4.1.5 Test Condition 3: Imaging Sensor

4.4.1.6 Test Condition 4: Approach Offset Angle

4.4.1.7 Test Condition 5: Glide Path Intercept Altitude

4.4.1.8 Test Condition 6: Crosswinds

4.4.1.9 Task 1: Pilot maneuvers the aircraft (if necessary) to optimize the interception of the runway centerline extension so that Centerline Track may be established prior to glideslope intercept. This may or may not require that the airport/runway is temporarily lost to one side of the SVS look angle.

4.4.1.10 Task 2: If required, pilot re-establishes contact with airport and runway to assess centerline intercept turn-in requirements.

4.4.1.11 Task 3: Pilot intercepts the runway centerline extension and turns the aircraft so that approach end of desired runway is within SVS Field of View and any residual aircraft track error is converging to centerline extension.

4.4.2 Criterion:

4.4.2.1 MOP 1: Aircraft track is brought to approximately runway centerline extension with a minimum of over- or under-shoot. Residual error is decreased toward zero as distance to runway decreases.

4.4.2.2 Report Content:

A. Pilot evaluation of capability.

B. Plan view of aircraft track with respect to runway.

C. Plot of aircraft heading as a function of range along runway centerline.

D. Performance correlation with image quality.

E. Performance correlation with weather conditions.

4.4.2.3 Data Elements:

A. Pilot commentary on runway detection task.

B. Position of aircraft with respect to runway.

C. Heading of aircraft as a function of distance from runway along the centerline.

D. Image quality measurement at runway detection and set points along path.

E. Weather conditions existing between aircraft and runway threshold at runway detection and set points along path.

4.4.2.4 Data Sources:

A. Subjective pilot opinion on commentary sheet and debrief.

B. INS, GPS, or mixed navigation sensors (position, true heading).

C. VHF Navigation Radio (Localizer Deviation)

D. HUD Camera RS-170 video.

E. RS-170 Video driving head down display.

F. Direct measurement total water content and particle size distribution sensors.

G. Site survey data of airport.

4.4.3 Rationale:

The pilot's primary cue in determining the runway centerline and its extension to the approach area is the synthetic image perspective. Since it represents the equivalent of the FAF in-bound course in a synthetic vision approach, aligning the aircraft with it may be a prerequisite to descent below the MSA/MDA.

When operating on existing precision instrument approaches, the centerline (localizer) capture is normally established based on the following TERPS criteria:

INTERCEPT DISTANCE PRIOR TO GLIDESLOPE INTERCEPT (TERPS §922)	
Maximum Angle Of Intersection	Minimum Distance To Glideslope Intersection
15°	1 mile
30°	2 miles
45°	3 miles
60°	4 miles
75°	5 miles
90°	6 miles

Category I ILS protection (Final Approach Area) is approximately 9° either side of charted final approach course. Full scale deflection on ILS Localizer varies from 3° to 1.5° as required to limit course width to 700' wide at runway threshold. ILS inbound course is also allowed to be offset up to 3° from runway centerline extension with intersection occurring 1100' to 1200' towards threshold from DH.

4.5 Runway Centerline Track

Can the pilot maneuver the aircraft to track along the desired runway's centerline during a functional prototype synthetic vision approach?

4.5.1 Scope:

4.5.1.1 Description: Pilot maintains acceptable horizontal alignment with runway centerline or its extension and attempt to close the offset distance from centerline or its extension to zero.

4.5.1.2 Initial Conditions: Airport Acquisition, Runway Acquisition, and Runway Centerline Capture have been completed. Runway centerline tracking may be required while performing the following vertical flight tasks:

- Level Flight (non-precision approaches)
- Initial Approach Descent (non-precision approaches)
- Glide Path Capture (non-precision approaches)
- Glide Path Track (all approaches)

4.5.1.3 Test Condition 1: Weather Conditions

4.5.1.4 Test Condition 2: Airport Surfaces

4.5.1.5 Test Condition 3: Imaging Sensor

4.5.1.6 Test Condition 4: Runway Intrusion

4.5.1.7 Test Condition 5: Crosswinds

4.5.1.8 Task 1: Pilot will use the SVS display to visually detect errors between aircraft track and runway centerline extension, and will maneuver the aircraft to reduce those errors to near zero.

4.5.1.9 Task 2: Pilot will interpret the SVS display to assure the runway is clear of obstructions.

4.5.2 Criterion:

4.5.2.1 MOP 1: Angle between aircraft track and runway centerline must remain small and should be converging to, or overlaying, the centerline (extended).

4.5.2.2 MOP 2: Any runway intrusion should be detected and the approach aborted.

4.5.2.3 Report Content:

A. Pilot evaluation of capability.

B. Plan view of aircraft track with respect to runway.

C. Plot of aircraft heading as a function of range along runway centerline.

D. Standard deviation of centerline tracking error.

E. Performance correlation with image quality.

F. Performance correlation with weather conditions.

G. Type of runway intrusions and probability of detection by pilot using the functional prototype SVS.

4.5.2.4 Data Elements:

A. Pilot Comentary on runway detection task.

B. Position of aircraft with respect to runway.

C. Heading of aircraft as a function of distance from runway along the centerline.

D. Image quality measurement at runway detection and set points along path.

E. Weather conditions existing between aircraft and runway threshold at runway detection and set points along path.

F. Type of intrusions and the range to runway threshold when pilot observed them.

4.5.2.5 Data Sources:

A. Subjective pilot opinion on commentary sheet and debrief.

B. INS, GPS, or mixed navigation sensors (position, true heading).

C. VHF Navigation Radio (Localizer Deviation)

D. HUD Camera RS-170 video.

E. RS-170 Video driving head down display.

F. Direct measurement total water content and particle size distribution sensors.

G. Site survey data of airport.

H. Event discrete or log of time (relatable to aircraft position) when a runway intrusion was detected.

4.5.3 Rationale:

Centerline tracking error should be comparable to VFR performance and should not be worse than the acceptable limits for IFR performance at the same altitude region.

Category I ILS protection (Final Approach Area) is approximately 9° either side of charted final approach course. Full scale deflection on ILS Localizer varies from 3° to 1.5° as required to limit course width to 700' wide at runway threshold. ILS inbound course is also allowed to be offset up to 3° from runway centerline extension with intersection occurring 1100' to 1200' towards threshold from DH.

4.6 Glide Path Capture

Can the pilot maneuver to intercept and capture the desired glide path to the runway while using the functional prototype synthetic vision system?

4.6.1 Scope:

4.6.1.1 Description: When flying on a non-precision approach, the pilot will use SVS imagery with HUD symbology to determine when the selected glide path angle intercepts the point of intended landing on the runway and will then transition the aircraft into a descent along that glide path.

4.6.1.2 Initial Conditions: Aircraft is configured for landing. Pilot is flying level at the MDA/MSA on a non-precision approach. The aircraft has been aligned to the runway centerline and is now tracking the centerline extension.

4.6.1.3 Test Condition 1: Weather Conditions

4.6.1.4 Test Condition 2: Airport Surfaces

4.6.1.5 Test Condition 3: Imaging Sensor

4.6.1.6 Test Condition 4: Glide Path Intercept Altitude

4.6.1.7 Task 1: Pilot determines when the chosen (nominally 3°) glideslope intercepts the point of intended landing on the approach end of the runway.

4.6.1.8 Task 2: Pilot maneuvers the aircraft into a descent that establishes the intercept of the desired glide path with the point of intended landing.

4.6.1.9 Task 3: The pilot establishes airspeed within ±5 knots of selected value.

4.6.2 Criterion:

4.6.2.1 MOP 1: The selected glide path angle intercepts the ground within a usable portion of the runway.

4.6.2.2 Report Content:

A. Pilot evaluation of capability.

B. Profile view of aircraft trajectory with respect to a "nominal" glide path to the runway.

C. Performance correlation with image quality.

D. Performance correlation with weather conditions.

4.6.2.3 Data Elements:

A. Pilot commentary on glide path capture task.

B. Aircraft position history with respect to the runway.

C. Aircraft altitude history.

D. Image quality measurements made at runway detection and at set points in the approach.

E. Weather conditions existing between aircraft and runway threshold at runway detection and set points along path.

4.6.2.4 Data Sources:

A. Subjective pilot opinion on commentary sheet and debrief.

B. INS, GPS, or mixed navigation sensors (position, true heading).

C. VHF Navigation Radio (Localizer Deviation)

D. UHF ILS Radio (Glideslope Deviation)

E. DADC (Barometric Altitude, Equivalent Airspeed)

F. Radar Altimeter (Radar Altitude)

G. HUD Camera RS-170 video.

H. RS-170 Video driving head down display.

I. Direct measurement total water content and particle size distribution sensors.

J. Site survey data of airport.

4.6.3 Rationale:

In order to qualify for lower than existing IFR minima, synthetic vision must provide the equivalent capabilities of those existing systems which provide very low minima. The approach used by the functional prototype SVS is to transform non-precision approaches into fully functional precision approaches with the added benefit of being able to see the runway. The primary method of creating the precision (glide path) element of the approach is the combination of the HUD situational symbology with the image of the runway plus the ability of the pilot to assimilate the data and produce both the guidance and control to achieve the desired glide path and its intercept with the runway landing area.

4.7 Glide Path Track

Can the pilot maintain a stabilized glide path to a usable portion of the runway while using the functional prototype SVS?

4.7.1 Scope:

4.7.1.1 Description: On all approaches the pilot must use the combination of HUD symbology and runway image to derive a glide path which intersects with a usable portion of the runway. The pilot must then maneuver the aircraft so that it maintains this glide path while constantly refining its intersection point with the runway to be in the usable landing area or overlying any electronic glideslope (precision approaches only). Airspeed must be maintained within acceptable limits of the desired value. To the extent possible, the runway should be checked clear of intrusions.

4.7.1.2 Initial Conditions: The aircraft is configured for landing. Runway detection and centerline capture have both occured and centerline track is in progress. The aircraft is either descending on an established electronic glideslope (precision approach) or has captured a nominal glide path to the runway (non-precision approach).

4.7.1.3 Test Condition 1: Weather Conditions

4.7.1.4 Test Condition 2: Airport Surfaces

4.7.1.5 Test Condition 3: Imaging Sensor

4.7.1.6 Test Condition 4: Runway Intrusions

4.7.1.7 Test Condition 5: ILS Guidance Cutout

4.7.1.8 Test Condition 6: Display Used

4.7.1.9 Task 1:

Precision Approach: While the pilot is still on the conventional precision approach, the HUD symbology and synthetic vision image of runway are used to determine position of the ILS glideslope intercept with the runway.

Non-Precsion Approach: The pilot selects an appropriate distance from the threshold of the runway for the glide path intercept to occur.

4.7.1.10 Task 2: Pilot maneuvers the aircraft to achieve the selected glide slope (descent rate) and to control that glide slope's intercept point on the runway.

4.7.1.11 Task 3: Pilot must maintain desired approach airspeed within acceptable limits.

4.7.1.12 Task 4: Pilot will assure that runway remains free of intrusions during the apporach.

4.7.2 Criterion:

4.7.2.1 MOP 1:

Precision Approach: Stabilized glide path is maintained sufficiently close to electronic glide slope to allow approach monitoring.

Non-Precision Approach: Stabilized glide path is maintained to a useable runway area.

4.7.2.2 MOP 2: Airspeed is maintained within an acceptable amount of the desired value.

4.7.2.3 MOP 3: Runway intrusions are detected.

4.7.2.4 Report Content:

A. Pilot evaluation of capability.

B. Profile view of aircraft trajectory with respect to a "nominal" glide path to the runway.

C. Standard deviation of precision glideslope tracking error.

D. Plot of airspeed versus range along centerline extension.

E. Performance correlation with image quality.

F. Performance correlation with weather conditions.

4.7.2.5 Data Elements:

A. Pilot commentary on glide path track task.

B. Aircraft position history with respect to the runway.

C. Aircraft air data (altitude,airspeed) history.

D. Planned V_{REF} approach speed.

E. Image quality measurements made at runway detection and at set points in the approach.

F. Weather conditions existing between aircraft and runway threshold at runway detection and set points along path.

4.7.2.6 Data Sources:

A. Subjective pilot opinion on commentary sheet and debrief.

B. INS, GPS, or mixed navigation sensors (position, true heading).

C. VHF Navigation Radio (Localizer Deviation)

D. UHF ILS Radio (Glideslope Deviation)

E. DADC (Barometric Altitude, Equivalent Airspeed)

F. Radar Altimeter (Radar Altitude)

G. HUD Camera RS-170 video.

H. RS-170 Video driving head down display.

I. Direct measurement total water content and particle size distribution sensors.

J. Aircraft Flight Manual

K. Site survey data of airport.

4.7.3 Rationale:

In order to qualify for lower than existing IFR minima, synthetic vision must provide the equivalent capabilities of those existing systems which provide very low minima. Currently autoland systems provide an electronic glideslope navigation signal and the associated guidance and control systems to fly it down to the flare altitude. The approach used by the functional prototype SVS is to transform non-precision approaches into fully functional precision approaches with the added capability of being able to see the runway.

The primary method of creating the precision (glide path) element of the approach is the combination of the HUD situational symbology with the image of the runway plus the ability of the pilot to assimilate the data and produce both the guidance and control to achieve the desired glide path and its intercept with the runway landing area.

If the desired angle and landing point are the same as a ILS *Glideslope* installation, then the two will overlay and the synthetic vision approach can be monitored using the ILS signal. However, if the pilot moves the point of intended landing, it then becomes impossible to use the ILS as a real time monitor.

4.8 Flare And Touchdown Maneuver

Can the pilot perform the flare to landing maneuver while using the functional prototype synthetic vision system?

4.8.1 Scope:

4.8.1.1 Description: On all approaches the flare maneuver is the pitch axis portion of the landing. The rate of descent is reduced so that main gear impact with the ground occurs at acceptable rates. Engine power is reduced and airspeed is allowed to decrease below the selected (V_{REF}) approach value. The aircraft is placed in a nose high attitude sufficiently to insure that the main gear make the initial contact with the runway.

4.8.1.2 Initial Conditions: Pilot is performing Runway Centerline Track and Glide Path Track.

4.8.1.3 Test Condition 1: Visibility

4.8.1.4 Test Condition 2: Weather Conditions

4.8.1.5 Test Condition 3: Airport Surfaces

4.8.1.6 Test Condition 4: Imaging Sensor

4.8.1.7 Test Condition 5: Zero/Zero Demonstration

4.8.1.8 Test Condition 6: Display Used

4.8.1.9 Test Condition 7: Day/Night

4.8.1.10 Test Condition 8: Flare Guidance Cue

4.8.1.11 Task 1: At a pilot determined altitude above the runway, a pitching maneuver is initiated which reduces the descent rate towards zero as the ground is approached. Associated with the pitching maneuver, a power reduction and airspeed decrease from V_{REF} may be initiated.

4.8.2 Criterion:

4.8.2.1 MOP 1: Transition from stabilized approach to touchdown is smooth and monotonically decreasing in altitude rate as altitude decreases.

4.8.2.2 MOP 2: Touchdown sink rate is controlled to between 0 and 4 feet/second.

4.8.2.3 MOP 3: Touchdown is accomplished in an acceptable portion of the runway.

4.8.2.4 Report Content:

A. Pilot evaluation of capability.

B. Hodograph of altitude versus altitude rate.

C. Value of sink rate at touchdown.

D. Longitudinal position of touchdown on runway measured from threshold.

E. Performance correlation with image quality.

F. Performance correlation with weather conditions.

4.8.2.5 Data Elements:

A. Pilot commentary on glide path capture task.

B. Altitude above ground level.

C. Altitude rate relative to ground.

D. Aircraft position history with respect to the runway threshold.

E. Image quality measurements made at runway detection and at set points in the approach.

F. Weather conditions existing at runway touchdown zone.

4.8.2.6 Data Sources:

A. Subjective pilot opinion on commentary sheet and debrief.

B. INS, GPS, or mixed navigation sensors (position, true heading).

C. VHF Navigation Radio (Localizer Deviation)

D. UHF ILS Radio (Glideslope Deviation)

E. DADC (Barometric Altitude, True Airspeed)

F. Radar Altimeter (Radar Altitude)

G. HUD Camera RS-170 video.

H. RS-170 Video driving head down display.

I. Direct measurement total water content and particle size distribution sensors.

J. Airport weather report (ceiling, Touchdown RVR, wind, gusts)

K. Main gear *Weight-On-Wheels* discrete.

L. Site survey data of airport.

4.8.3 Rationale:

Achieving performance of the flare maneuver that is equivalent to existing VFR and/or autoland standards is expected to be a prerequisite for low visibility synthetic vision landings.

4.9 Lateral Landing Maneuver

Can the pilot effect the lateral landing of the aircraft while flying a synthetic vision approach?

4.9.1 Scope:

4.9.1.1 Description: The lateral landing maneuver is the collection of roll and yaw actions that complement the flare and touchdown maneuver (section 4.9.0) in getting the aircraft physically in contact with the ground.

4.9.1.2 Initial Conditions: Runway Centerline Track is in progress. Flare/Touchdown Maneuver has been initiated and continues simultaneously with the lateral landing maneuver.

4.9.1.3 Test Condition 1: Visibility

4.9.1.4 Test Condition 2: Weather Conditions

4.9.1.5 Test Condition 3: Airport Surfaces

4.9.1.6 Test Condition 4: Imaging Sensor

4.9.1.7 Test Condition 5: Zero/Zero Demonstration

4.9.1.8 Test Condition 6: Display Used

4.9.1.9 Test Condition 7: Day/Night

4.9.1.10 Test Condition 8: Crosswinds

4.9.1.11 Task 1: Prior to main gear touchdown, the aircraft is de-crabbed as necessary so as to get the ground track and yaw attitude co-incident with the runway heading as the landing gear alight on the runway.

4.9.1.12 Task 2: Roll angles are constrained to prevent wing tip strikes.

4.9.2 Criterion:

4.9.2.1 MOP 1: Lateral touchdown position within acceptable limits.

4.9.2.2 MOP 2: Aircraft heading at touchdown is aligned with runway centerline within acceptable limits.

4.9.2.3 MOP 3: Touchdown roll angle is within acceptable limits.

4.9.2.4 MOP 4: Side loads imposed upon the gear are within normal operating limits.

4.9.2.5 Report Content:

A. Pilot evaluation of capability.

B. Lateral position of touchdown on runway measured from centerline presented as a scatter plot.

C. History of heading deviation from runway heading below 50 feet agl.

D. History of roll angle below 50 feet agl.

E. Peak sideload imposed on gear at touchdown.

F. Performance correlation with image quality.

G. Performance correlation with weather conditions.

4.9.2.6 Data Elements:

A. Pilot commentary on lateral landing task.

B. Lateral position with respect to runway centerline.

C. Heading difference from that of runway centerline.

D. Aircraft position history with respect to the runway threshold.

E. Image quality measurements made at runway detection and at set points in the approach.

F. Weather conditions existing at runway landing zone.

4.9.2.7 Data Sources:

A. Subjective pilot opinion on commentary sheet and debrief.

B. INS, GPS, or mixed navigation sensors (attitude, position, magnetic heading, lateral acceleration).

C. VHF Navigation Radio (Localizer Deviation)

D. Radar Altimeter (Radar Altitude)

E. HUD Camera RS-170 video.

F. RS-170 Video driving head down display.

G. Direct measurement total water content and particle size distribution sensors.

H. Airport weather report (ceiling, RVR, wind, gusts)

I. Main gear *Weight-On-Wheels* discrete.

J. Site survey data of airport.

4.9.3 Rationale:

In order for a synthetic vision system to support low visibility landings, it must provide the pilot with the capability to provide lateral and yaw control of the aircraft that is equivalent to visual or existing autoland systems.

Lateral/roll "landing" maneuvers have been separated from the vertical flare and touchdown maneuvers since the strategies, mechanization, and analysis are significantly different.

4.10 High Speed Rollout

Can the pilot control the aircraft's lateral alignment and deceleration during the high speed rollout using synthetic vision?

4.10.1 Scope:

4.10.1.1 Description: Aircraft is placed into a decelerating configuration, usually involving wing spoilers, reverse thrust devices, and wheel brakes. Rudder, nose wheel steering, and differential braking are used to track the runway centerline.

4.10.1.2 Initial Conditions: Aircraft has completed flare and landing to the point where weight is on all landing gear.

4.10.1.3 Test Condition 1: Visibility

4.10.1.4 Test Condition 2: Weather Conditions

4.10.1.5 Test Condition 3: Airport Surfaces

4.10.1.6 Test Condition 4: Imaging Sensor

4.10.1.7 Test Condition 5: Zero/Zero Demonstration

4.10.1.8 Test Condition 6: Display Used

4.10.1.9 Test Condition 7: Day/Night

4.10.1.10 Task 1: Pilot selects and uses appropriate methods to maintain the aircraft on the runway and converge to the centerline. These may include rudder deflection, nose wheel steering, and differential braking.

4.10.1.11 Task 2: Pilot selects and uses appropriate methods to decelerate the aircraft; including reverse thrust, wing spoilers, speed brakes, and wheel braking.

4.10.2 Criterion:

4.10.2.1 MOP 1: Nose wheel tracks the runway centerline within acceptable limits.

4.10.2.2 Report Content:

A. Pilot evaluation of capability.

B. Performance correlation with image quality.

C. Performance correlation with weather conditions.

4.10.2.3 Data Elements:

A. Pilot commentary on high speed rollout task.

B. Image quality measurements made at runway detection and at set points in the approach.

C. Weather conditions existing at runway.

4.10.2.4 Data Sources:

1. Subjective pilot opinion on commentary sheet and debrief.
2. HUD Camera RS-170 video.
3. RS-170 Video driving head down display.
4. Direct measurement total water content and particle size distribution sensors.
5. Airport weather report (ceiling, RVR, wind, gusts)
6. Site survey data of airport.

4.10.3 Rationale:

The ability to manage the high speed rollout will be a major factor in determining if synthetic vision systems can be used for Category IIIa,b,c capabilities. The primary concern is that sufficient recognition of the runway area is given to the pilot that he can handle the normal rollout as well as blown tires, engine failure's, or heavy braking.

4.11 Ground Operations

Can the pilot perform low speed ground operations (rollout completion, taxi to/from the ramp) while relying on synthetic Vision?

4.11.1 Scope:

4.11.1.1 Description: Pilot will use the synthetic vision image to navigate through the runway/taxiway system. Reasonable assurance of clearance from typical obstructions or intrusions on the taxi way should be detected.

4.11.1.2 Initial Conditions: High Speed Rollout has slowed the aircraft to Taxi-speed. Thrust reversers are stowed, nose wheel steering is active, and only wheel braking is in use.

4.11.1.3 Test Condition 1: Visibility

4.11.1.4 Test Condition 2: Weather Conditions

4.11.1.5 Test Condition 3: Airport Surfaces

4.11.1.6 Test Condition 4: Imaging Sensor

4.11.1.7 Test Condition 5: Zero/Zero Demonstration

4.11.1.8 Test Condition 6: Display Used

4.11.1.9 Test Condition 7: Day/Night

4.11.1.10 Task 1: Pilot uses functional prototype synthetic vision image to maneuver the aircraft in accordance with the ATC taxi clearnace. This includes:

A. Determining and maintaining the aircraft on the centerline of taxiway.

B. Estimating turning point for transition to intersecting taxiways.

4.11.1.11 Task 2: Pilot verifies that no aircraft or vehicle obstruction exists in the taxiway path for a distance commensurate with his stopping distance.

4.11.1.12 Task 3: Pilot scans for and identifies pavement repair barriers and or chuck holes and maneuvers the aircraft so that they are avoided.

4.11.2 Criterion:

4.11.2.1 MOP 1: Aircraft must be able to maneuver successfully.

4.11.2.2 Report Content:

A. Pilot evaluation of capability.

B. Performance correlation with image quality.

C. Performance correlation with weather conditions.

4.11.2.3 Data Elements:

A. Pilot commentary on glide path capture task.

B. Image quality evaluation of baseline ground target.

C. Weather conditions existing at runway.

4.11.2.4 Data Sources:

A. Subjective pilot opinion on commentary sheet and debrief.

B. HUD Camera RS-170 video.

C. RS-170 Video driving head down display.

D. Airport weather report (ceiling, RVR, wind, gusts)

E. Site survey data of airport.

4.11.3 Rationale:

Achievement of very low visibility landings is not significant unless effective ground movement of the aircraft to/from the ramp area is possible. It is important to determine if SVS technologies have the potential to allow aircraft to reliably maneuver on the airport surface in very low visibilities without the necessity of special lighting and/or markings. This includes the ability to detect other aircraft or reasonable obstructions which might intrude into a runway or taxiway.

4.12 Takeoff Maneuver

Can a pilot perform a takeoff when relying on synthetic vision?

4.12.1 Scope:

4.12.1.1 Description: The SVS is used to taxi the aircraft onto the active runway, align it with the runway heading, and maintain runway center as during the takeoff roll. The SVS display remains primary during the go/abort decision, rotation, and V_2 capture.

4.12.1.2 Initial Conditions: Taxi is completed and aircraft is correctly configured for takeoff.

4.12.1.3 Test Condition 1: Visibility

4.12.1.4 Test Condition 2: Weather Conditions

4.12.1.5 Test Condition 3: Airport Surfaces

4.12.1.6 Test Condition 4: Imaging Sensor

4.12.1.7 Test Condition 5: Zero/Zero Demonstration

4.12.1.8 Test Condition 6: Runway Intrusions

4.12.1.9 Test Condition 7: Display Used

4.12.1.10 Test Condition 8: Day/Night

4.12.1.11 Task 1: Pilot taxis aircraft onto active runway and aligns aircraft with the runway centerline.

4.12.1.12 Task 2: Pilot assures that no runway intrusion exists.

4.12.1.13 Task 3: Pilot performs the takeoff while using the functional prototype to provide alignment to runway centerline.

4.12.2 Criterion:

4.12.2.1 MOP 1: Runway intrusions are detected.

4.12.2.2 MOP 2: Aircraft tracks the runway centerline within acceptable limits.

4.12.2.3 Report Content:

A. Pilot evaluation of capability.

B. Performance correlation with image quality.

C. Performance correlation with weather conditions.

4.12.2.4 Data Elements:

A. Pilot commentary on takeoff task.

B. Image quality evaluation of baseline ground target.

C. Weather conditions existing at runway.

4.12.2.5 Data Sources:

A. Subjective pilot opinion on commentary sheet and debrief.

B. HUD Camera RS-170 video.

C. RS-170 Video driving head down display.

D. Airport weather report (ceiling, RVR, wind, gusts)

E. Site survey data of airport.

4.12.3 Rationale:

If lower landing minima are achieved without comparable takeoff capability, the enconomic benefit of synthetic vision will be substantially decreased.

5. EXPERIMENTS

The *Experiments* of this section are primarily measurements of equipment capabilities and do not require the statistical repetition typical of the combined human/machine performance assessments presented in Section 4. The experiments compliance to the experimental design objectives is as follows:

A. Physical phenomena of millimeter wavelength radar imaging of airport scenes at low grazing angles.

1. Normalized Radar Cross Section (RCS)
2. Reflectivity (σ^0)
3. Path Attenuation
4. Volumetric Backscatter

B. Performance of millimeter wavelength radar and its image processing under operational conditions.

1. Runway Contrast To Surroundings
2. Sharpness of Runway Edges
3. Variability of Surroundings and Runway

These measurements are made using both the raw radar return data from the receiver system, and from the video output of the signal processing system.

C. Performance of the forward looking infra-red sensor under operational conditions.

1. Runway Contrast To Surroundings
2. Sharpness of Runway Edges
3. Variability of Surroundings and Runway

These measurements are made at the video output of the FLIR system.

D. Determine image quality in a manner that can be applied to human performance evaluations and generic synthetic vision system designs.

1. Measure HUD combined image and outside scene from a position equivalent to the pilot's eyeball.
2. Establish a metric characterizing all major elements of image quality.
   - Contrast between runway and its surroundings.
   - Sharpness of the edges of the runway.
   - Signal to variability ratio.

5.1 Standard Measurement Methods

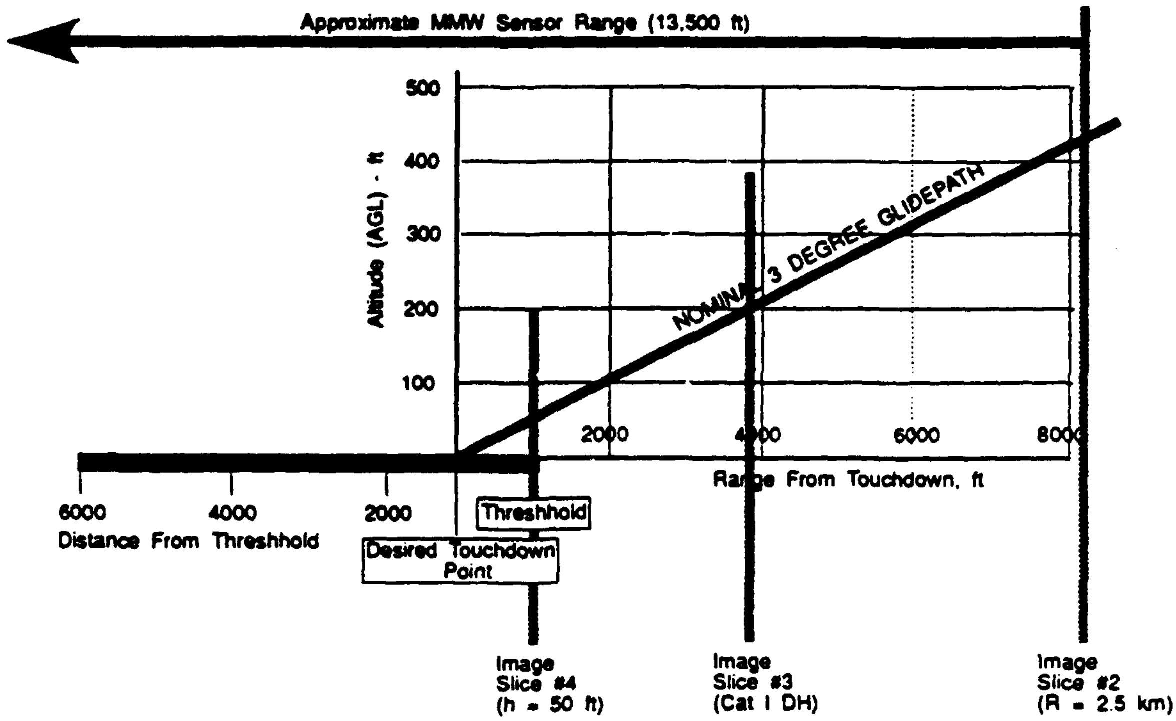
The detailed experiment descriptions in Sections 5.3 through 5.10 use similar measurement methods. This section describes those standard measurements that are applicable to all of the experiments unless otherwise stated.

5.1.1 Imaging Performance Comparisons:

Develop a method that allows the comparison of imaging performance between different sensors, runway / terrain combinations, or intervening weather.

A set of standard ranges from the runway threshold has been established where measurements for imaging performance comparsion will be taken. With constant range, the primary variables are the sensor under test, the runway and surrounding terrain characteristics, and the intervening

weather. The choice for the standard ranges is driven by the desire to make measurements showing any image "vanishing point" in weather conditions varying from clear through heavy fog or rain. Figure 5-1 shows the ranges and geometery that will be used for these standard measurements.



Note: Image Slice #1 is at pilot detection

A. Image Slice #2 is taken at a ground range of 2.5 km (8,200 feet) from the desired touchdown point, measured along the centerline extension. Assuming a minimal runway length of 6000 feet, this places the sensor range to the runway scene (approach to departure ends) between 7,200 and 13,200 feet and having grazing angles from 3.3° to 1.8°. See Figure 5-3 for additional statistics.

B. Image Slice #3 is taken coincident with the nominal Category I ILS decision height at a ground range of 1.2 km (4,000 feet) from touchdown. Under the scenarios, this will be the point at which the sensor must be providing the pilot with an image of at least the approach end of the runway if the approach is to continue. Notice that there is at least 2000 feet of runway range overlap between the Image Slice #2 and Image Slice #3 measurements to insure that any vanishing point is correctly measured. The pertinent range and grazing angle statistics are given in Figure 5-3.

C. Image Slice #4 is taken as the aircraft passes over the runway threshold at a ground range of 0.3 km (1,000 feet) from touchdown and 50 feet altitude. It is coincident with the decision height of many Category IIIa approaches, and provides measurements especially applicable to flare and landing performance. The pertinent range and grazing angle statistics are given in Figure 5-2.

Figure 5-1. Standard Data Measurement Locations

Image Quality And Radar Data Measurement Parameters						
Image Slice	Range To Touchdown	Altitude	Approach Threshold Range	Approach Threshold Angle	Departure Threshold Range	Departure Threshold Angle
#1	Varies based on when pilot calls that he has runway in sight					
#2	2.5 km / 8,200 ft	125 m / 410 ft	2.2 km / 7,200 ft	3.26°	4.0 km / 13,200 ft	1.78°
#3	1.2 km / 4,000 ft	61 m / 200 ft	0.9 km / 3,000 ft	3.81°	2.7 km / 9,000 ft	1.27°
#4	0.3 km / 1,000 ft	15 m / 50 ft	-	90.00°	1.8 km / 6,000 ft	0.48°

Figure 5-2. Image Quality And Radar Data Measurement Parameters

5.1.2 Image Quality Required For Recognition:

Provide measurements that allow the correlation of image quality with the ability of a pilot to operationally recognize the runway.

The operational requirement to have the pilot call when he "has the runway" supports this measurement. On his call, a marker is placed on the data allowing the image quality of the sensor (FLIR, Radar, and raw Radar) to be captured and evaluated. The Image Slice #1 in Figure 5-1 above is the variable distance image sample associated with the pilot's callout. The range to threshold may be considerably greater than that of the other image slices in good weather, or somewhere between the other slices in in weather or unfavorable runway/terrain combinations.

5.1.3 Runway Scene Measurements:

Establish specific measurement areas of the runway which support comparisions and evaluation of image quality. Each of the three fixed *Image Slices* as well as the variable "Runway-In-Sight" *Image Slice* will be analyzed at three areas of the runway as shown in Figure 5-3:

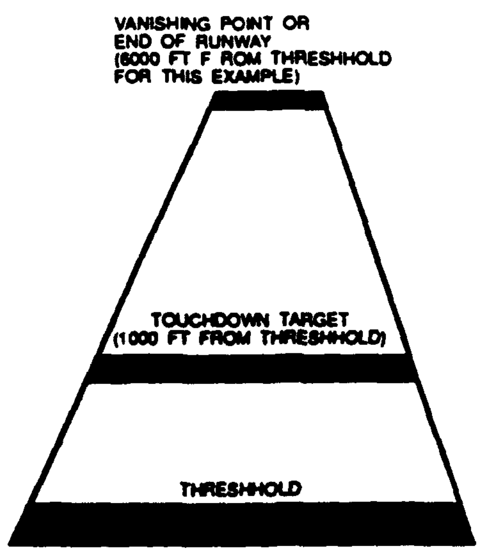


Figure 5-3. Runway Scene Measurements

A. The *Runway Threshold* is used (except in Image Slice #4, where it is directly below the aircraft) because of its importance in recognizing the runway, aligning the aircraft to it, and establishing where to place the glide path reference.

B. The *Touchdown Zone*, which is nominally 1000 feet down the runway from the approach end.

C. The *Vanishing Point* is the point at which the runway blends in with the surrounding terrain.

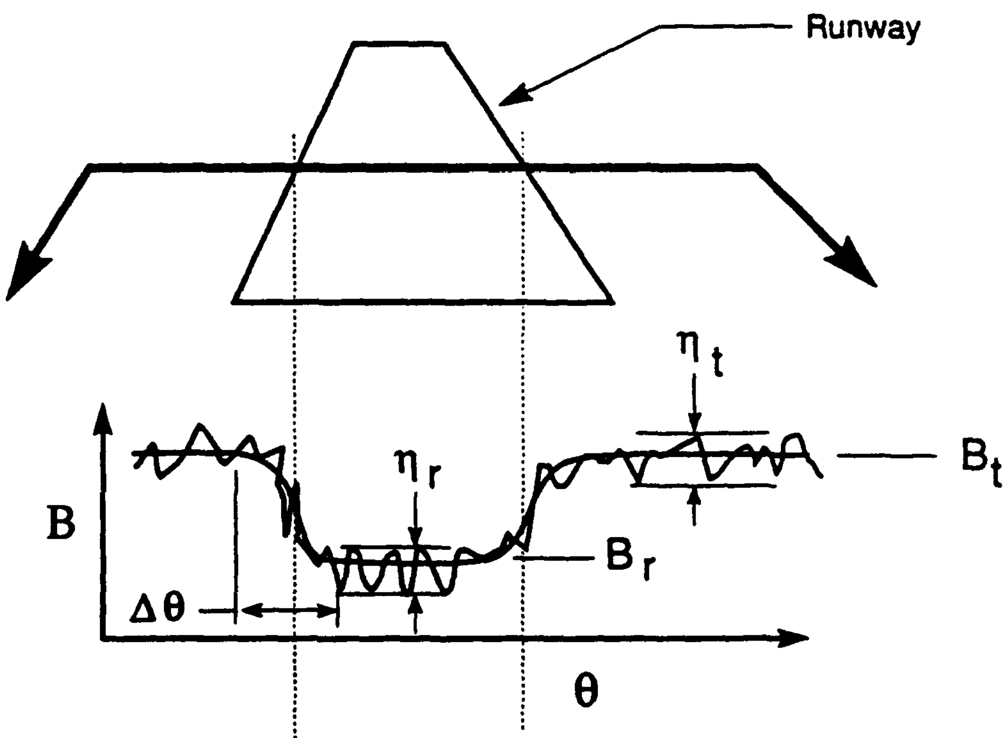
1. On video data, vanishing point is determined by human review of the video image.
2. Raw Radar data will be transformed into B-scope (plan view) format and analyzed in the same manner as the video. The difference between raw radar vanishing point and the processed radar video vanishing point gives a first order assessment of the capabilities of the radar signal processing system.

If the entire runway is visible, then the departure (far) end of the runway is used in lieu of the vanishing point.

5.1.4 Contrast, Sharpness, Variability Determinations:

Establish standard measurements for Contrast, Sharpness, and Variability for all (FLIR, Radar, or raw Radar) image quality measurements.

Both FLIR and Radar video and digital raw radar measurements will be performed using the same general approach. As shown in Figure 5-3, each of the three areas of the runway will be identified and then analyzed for the signal return. Figure 5-4 shows the measurement technique for a single line of pixels. The actual measurements will use the averaged values from multiple pixel lines to reduce the effects of random signal disturbances.



C = Contrast = $|(B_r - B_t)/B_t|$

S = Sharpness = $1/\Delta\theta$

η_t = Variability of Terrain Returns = RMS Variation In Brightness

η_r = Variability of Runway Returns = RMS Variation In Brightness

B = Brightness (Intensity) of signal

B_t = Average Brightness of Terrain

B_r = Average Brightness of Runway

θ = Yaw angle with respect to aircraft fuselage reference line.

$\Delta\theta$ = Transition angle for sharpness

Figure 5-4. Contrast, Sharpness, And Variability Measurement Methods

5.2 Common Data Element Requirements

The detailed experiment descriptions in Sections 5.3 through 5.10 have many data requirements which are very similar. This section describes a common baseline that is applicable to all of the experiment's data element requirements unless otherwise stated.

5.2.1 FLIR, Radar, and Pilot View Imaging Sources

The functional prototype synthetic vision system design provides flexibility in selection and recording of the sensor data on the aircraft. Figure 5-5 shows the imaging sources, the available data streams, and how they will be captured for the data reduction and analysis. Notice that all video is recorded on "High 8 Video Cassette Recorders" using the 8 mm tape format. Digital (raw) radar data is sampled approximately once every four seconds and is stored on a PCM Instrumentation Recorder. The Pilot View Video is obtained by using a mirror arrangement to sample the pilot's combined video and outside scene and transmit it to a video camera.

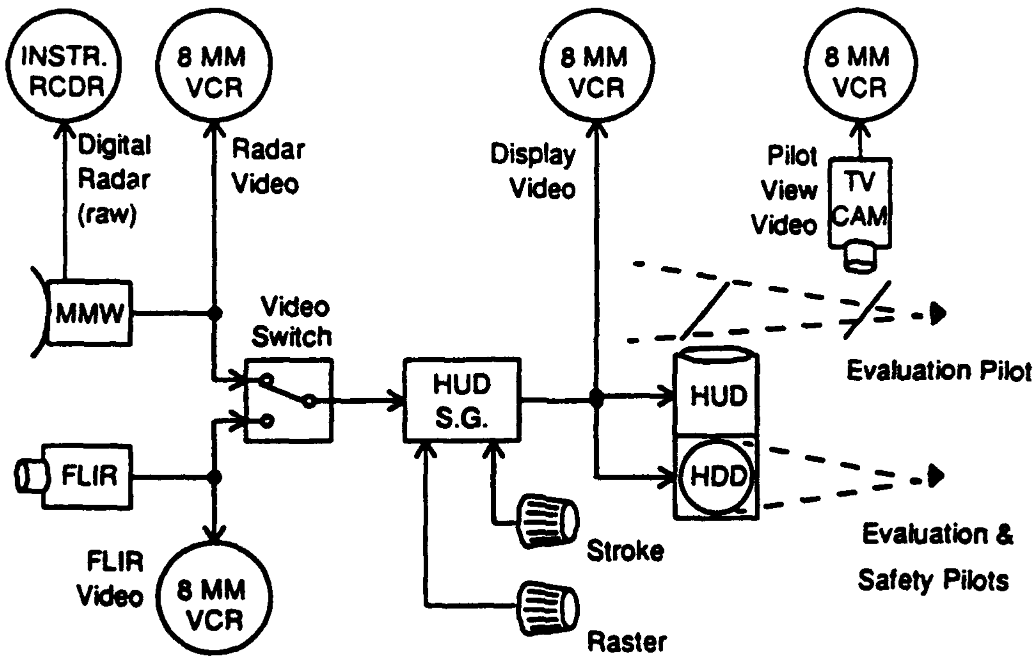


Figure 5-5. Imaging Sensor Sources, Displays, and Recorders

5.2.2 Radar System Data Requirements

The following vendor's calibrated data characterizing unit performance is required for analysis of

the radar imaging sensor(s):

A. Relative calibration of data using RTC.†

B. "Raw" radar return data in digital format.†

C. Basic Radar System Parameters.†

5.2.3 Aircraft Data Requirements

A. Aircraft Attitude in Euler angles (pitch, roll, yaw).

B. Position with respect to runway scene

C. Altitude relative to runway scene; including barometric, radar, inertial, and any blended composition used by the radar sensor(s).

D. Ground speed and direction (true or magnetic as is used by sensor).

E. Heading and track angle (true or magnetic as is used by sensor).

5.2.4 Weather Data Requirements

A. Real time sampling of weather data being experienced by the aircraft.
- Total water content measurement.
- Particulate dropsize distribution.
- Humidity
- Temperature

B. Computation of atmospheric water content integrated along the glide path between aircraft and runway scene.
- Liquid water content for fog.
- Rainfall Rate for rain.
- Equivalent rainfall rate for other precipitation.

5.2.5 Ground Truth (Survey) Data

A. General information about each airport/runway/approach.
- X, Y, and Z of range references in scene.
- Latitude, Longitude, and Altitude of standard (calibration) reflectors in the scene.
- Latitude, Longitude, and Altitude of significant objects along approach (Tower, antenna supports, glideslope transmitter building, etc).
- Time tagged notes of significant runway or taxiway traffic during each approach.

B. Runway Description.
- Latitude, Longitude, and Altitude of approach, touchdown, and departure areas of each runway.
- Heading of each runway (magnetic or true, as used by sensor).
- Type of construction (Asphalt, Concrete, etc.).
- Condition and roughness (Smooth, Cracked, grooved, etc.).
- Surface water or snow depth and condition.
- Percent free water content (snow only).

C. Terrain Description.
- Type of terrain (grass, dirt, clay, scrub brush, asphalt, concrete, etc.).
- Condition and roughness (green, dry, smooth, cracked, etc.)
- Surface water or snow depth and condition.

---

† Proprietary to sensor vendor.

- Percent free water content (snow only).

D. Supporting photographs or video tapes of the the conditions.

5.2.6 Data Recording

Time tagging between aircraft data and each video image or raw radar data snapshot must be provided.

5.3 Radar Cross Section (RCS)

Determine the absolute radar cross section of passive corner reflectors placed in the runway approach scene. Identify and calibrate permanent targets in the scene as secondary RCS standards.

5.3.1 Purpose:

The returned signal from calibrated corner reflectors is used to establish absolute measurements of the functional prototype SVS radar performance. While themselves proprietary to the radar manufacturer, these references are then used in the computation of normalized physical phenomena which are independent of the specific radar performance and will be included in the public report.

The inclusion of corner reflectors in the scene may disturb the operational assessment, and will only be used on a limited number of approaches. Other natural targets in the scene (tower, transmitter buildings, etc) will be selected and analyzed to determine their RCS relative to the corner reflectors. This allows them to be used as secondary RCS standards when the corner reflectors are not deployed.

5.3.2 Methodology:

A series of three corner reflector targets will be set up along, and to one side, of the runway. During an approach, the digital radar data will be sampled at the standard ranges and processed to determine the RCS of the point reflectors. Additional processing will be done to identify and determine the relative RCS of natural reflectors within the scene.

5.3.3 Additional Test Conditions:

A. Clear weather approach is mandatory.

B. Corner.reflectors must be deployed and positions mapped.

5.3.4 Report Content:

A. Absolute RCS of corner reflectors.‡

B. Relative RCS of natural reflectors with respect to corner reflectors.‡

5.3.5 Data Elements:

No requirements beyond the generic ones stated in Section 5.2.

5.3.6 Rationale:

Absolute radar cross section is a necessary measurement to allow the remainder of the radar experiments results to be computed.

Significant flight time can be shared without the possibility of contaminating the operational assessment if scene enhancements like corner reflectors are not present. This is the basis for doing the absolute measurements on single, clear weather approaches, and then calibrating natural reflectors as secondary standards to be referenced during the actual weather approaches.

‡ Included only in Proprietary Report.

5.4 Reflectivity (Normalized RCS)

Determine the normalized radar cross section (reflectivity or σ^0) of the runway surface and the surrounding terrain.

5.4.1 Purpose:

Determine and catalog the basic reflectivity of typical airport surfaces and the surrounding terrains. Determine the changes which occur in differing weather conditions.

5.4.2 Methodology:

The methodology of this experiment is the same as the RCS Experiment (Section 5.5.3). The analysis will process areas of both runway and the surrounding terrain as shown in Figure 5-6:

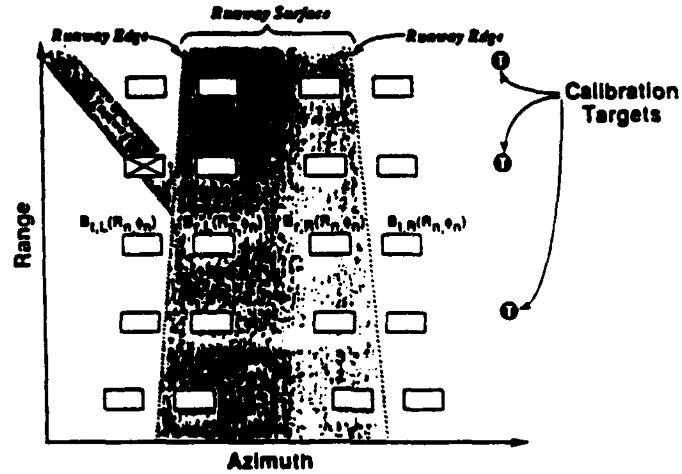


Figure 5-6. Basic Radar Data Processing for Reflectivity Metrics

This technique provides multiple reflectivity measurements along the length of the runway for each image analyzed.

5.4.3 Test Conditions

A. Clear weather approach is mandatory.

B. Corner reflectors must be deployed and positions mapped.

5.4.4 Report Content

The reflectivity of the airport surfaces and surrounding terrains will be correlated against variables of interest. A typical example may be correlation of various surface reflectivities with differing depression angles.

5.4.5 Data Elements

No requirements beyond the generic ones stated in Section 5.2.

5.4.6 Rationale

Radar reflectivity of airport targets at the low grazing angles needed for approach and landing use have not been publically documented. The numbers obtained from this effort should have widespread use in both government and industry.

5.5 Path Attenuation

Measure the path attenuation between the radar and the runway area under varying weather conditions.

5.5.1 Purpose:

Determines the effective attenuation that an atmospheric condition presents to electro-magnetic fields at the frequency of the functional prototype sensor. The experiment also characterizes this attenuation in terms of the actual slant range weather and also allows it to be related to standard ground observations.

5.5.2 Methodology:

The clear weather data gathered for *Radar Cross Section* and *Reflectivity* experiments are used as baselines to additional measurements made at the four standard "image slices" while flying through actual weather. The use of the secondary reflector standards developed in the *Radar Cross Section* experiment allows this experiment to piggy-back on the operational assessment approaches in real weather.

The runway and surrounding terrain will be processed the same as in the Radar Cross Section experiment, shown in Figure 5.6

5.5.3 Test Conditions

A. Approaches flown through actual weather that is challenging to the sensor(s).

B. Existence of either primary or calibrated secondary radar reflector standards within the field of view at the airport/runway being approached.

5.5.4 Report Content

Attenuation will be correlated to conditions found to be of interest as well as models.

5.5.5 Data Elements

No requirements beyond the generic ones stated in Section 5.2.

5.5.6 Rationale

Primary design requirements for future synthetic vision radar systems must consider the degradation of radar signals due to interaction with the atmosphere. The near real time measurement of detailed weather conditions along the glide path make the attenuation coefficients of significant interest.

5.6 Volumetric Backscatter

Measure the radar signal backscatter from various atmospheric conditions and calibrate it to normal unit volume.

5.6.1 Purpose:

Determine the volumetric backscatter (reflectivity from a unit volume) of differing weather conditions at the frequencies used by the functional prototype radar sensor(s). Use the measured backscatter and detailed weather environment to allow comparison with mathematical predictions.

5.6.2 Methodology:

The clear weather data gathered for *Radar Cross Secticn* and *Reflectivity* experiments are used as baselines to additional measurements made at the four standard "image slices" while flying through actual weather. The use of the secondary reflector standards developed in the *Radar Cross Section* experiment allows this experiment to piggy-back on the operational assessment approaches in real weather.

The runway and surrounding terrain will be processed the same as in the Radar Cross Section experiment, shown in Figure 5.6

5.6.3 Test Conditions

A. Approaches flown through actual weather that is challenging to the sensor(s).

B. Existence of either primary or calibrated secondary radar reflector standards within the field of view at the airport/runway being approached.

5.6.4 Report Content

Backscatter will be correlated to conditions found to be of interest as well as models.

5.6.5 Data Elements

No requirements beyond the generic ones stated in Section 5.2.

5.6.6 Rationale

Backscatter due to the radar signal's interaction with the atmosphere effectively increases the noise input seen at the radar receiver, adversely affecting the signal to noise ratio, one of the primary radar design parameters needed for next generation systems.

5.7 Runway Contrast To Surroundings

Measure the contrast between the runway and its surroundings as measured by the SVS sensors and as seen by the pilot flying.

5.7.1 Purpose:

A. Provide contrast data as a key ingredient in the assessment of image quality.

B. Provide a first order assessment of how changes in surfaces or conditions affect the capability of a sensor.

C. Estimate effectiveness of any signal processing performed on the raw radar signal in creating the radar video output‡.

5.7.2 Methodology:

Contrast measurements will be made from the following sources on every approach:

A. Radar Sensor Video Output

B. FLIR Sensor Video Output

C. Pilot View Video Camera Output

Digital radar data (raw) will be processed on a selected 40 to 50 approaches at the four standard *Image Slice* positions.

The details of the measurement method are given in Section 5.1.

5.7.3 Test Conditions

A. Weather Conditions

B. Airport Surfaces

C. Day/Night

5.7.4 Report Content

Contrast data from this experiment will be presented as a correlating factor in many of the other performance and experiment reports. Multiple plots may be made to show differing correlations with the test conditions.

5.7.5 Data Elements

No requirements beyond the generic ones stated in Section 5.2.

5.7.6 Rationale

Contrast is one of the fundamental measurements in predicting human or machine recognition capability. It also provides an effective first order approximation of a sensor's performance as the operating conditions change.

‡ Included only in Proprietary Report.

5.8 Sharpness of Runway Edges

Measure the sharpness the runway edge transition to its surroundings as measured by the SVS sensors and as seen by the pilot flying.

5.8.1 Purpose:

A. Provide sharpness data as a key ingredient in the assessment of image quality.

B. Provide a first order assessment of how changes in surfaces or conditions affect the capability of a sensor.

C. Estimate effectiveness of any signal processing performed on the raw radar signal in creating the radar video‡ output.

5.8.2 Methodology:

Sharpness measurements will be made from the following sources on every approach:

A. Radar Sensor Video Output

B. FLIR Sensor Video Output

C. Pilot View Video Camera Output

Digital radar data (raw) will be processed on a selected 40 to 50 approaches at the four standard *Image Slice* positions.

The details of the measurement method are given in Section 5.1.

5.8.3 Test Conditions

A. Weather Conditions

B. Airport Surfaces

C. Day/Night

5.8.4 Report Content

Sharpness data from this experiment will be presented as a correlating factor in many of the other performance and experiment reports. Multiple plots may be made to show differing correlations with the test conditions.

5.8.5 Data Elements

No requirements beyond the generic ones stated in Section 5.2.

5.8.6 Rationale

Sharpness of edge transitions is one of the fundamental measurements in predicting human or machine recognition capability. It also provides an effective first order approximation of a sensor's performance as the operating conditions change.

‡ Included only in Proprietary Report.

5.9 Variability Of Signals

Measure the variability of the runway signal and the runway surrounding's signal as measured by the SVS sensors and as seen by the pilot flying.

5.9.1 Purpose:

A. Provide variability data as a key ingredient in the assessment of image quality.

B. Provide a first order assessment of how changes in surfaces or conditions affect the capability of a sensor.

5.9.2 Methodology:

Variability measurements will be made from the following sources on every approach:

A. Radar Sensor Video Output

B. FLIR Sensor Video Output

C. Pilot View Video Camera Output

Digital radar data (raw) will be processed on a selected 40 to 50 approaches at the four standard *Image Slice* positions.

The details of the measurement method are given in Section 5.1.

5.9.3 Test Conditions

A. Weather Conditions

B. Airport Surfaces

C. Day/Night

5.9.4 Report Content

Variability data from this experiment will be primarily used in generation of image quality figures of merit. Correlations with typical parameters such as surfaces, weather, or range will be shown as they are found to be meaningful.

5.9.5 Data Elements

No requirements beyond the generic ones stated in section 5.5.0.

5.9.6 Rationale

Variability of signals from surfaces is one of the fundamental measurements in predicting human or machine recognition capability. While a first examination of this parameter and its uses may look, taste, and feel like *noise*, there are significant differences:

A. Noise is totally random and is based on thermal or space based sources.

B. Variability (as used here) contains an element of noise, but also has the change in return due to such things as the wind blowing the grass. These are not necessarily random and may even contain exploitable information in the form of visual texture.

5.10 Image Quality Assessment

Measure the image quality as seen by the pilot in both HUD and HDD situations.

5.10.1 Purpose:

A. Provide the parameter that is expected to be the primary correlator to achieved operational performance.

B. Provide a metric that will allow data taken on this program to be reasonably applied to future programs.

5.10.2 Methodology:

Image quality measurements will be made from the following sources on every approach:

A. Radar Sensor Video Output

B. FLIR Sensor Video Output

C. Pilot View Video Camera Output

Digital radar data (raw) will be processed on a selected 40 to 50 approaches at the four standard *Image Slice* positions.

This measurement builds on the Contrast, Sharpness, and Variability measurements given in Section 5.1.

The single figure of merit for image quality is of the form: $IQ = f_1(C) \cdot f_2(S_h) \cdot f_3(SVR)$ where:

$f_1(C)$ is contrast, varying from 0 to 1.

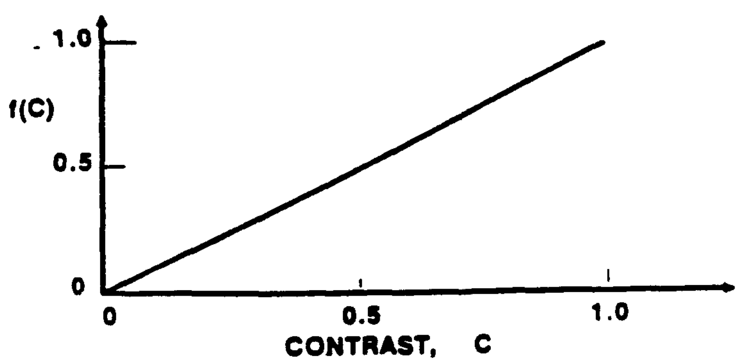


Figure 5-7. Contrast Transfer Function for Image Quality Metric

$f_2(S_h)$ is a measure of sharpness, varying from 0 (poor) to 1 (human visual acuity) as $S_h = 1/\theta$ varies from 0 to 60 $(DEG)^{-1}$

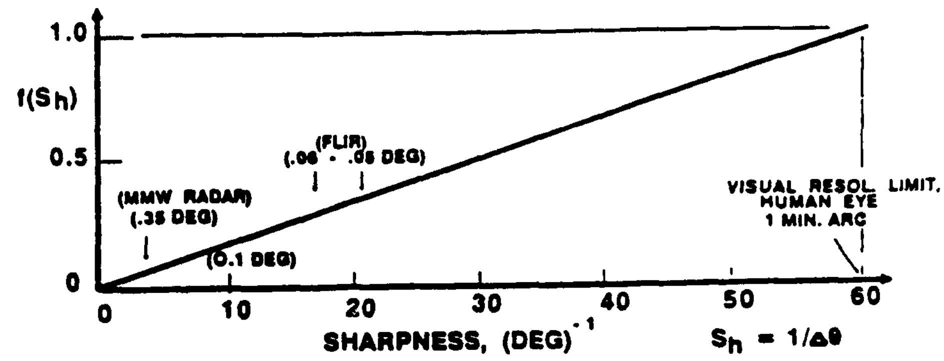


Figure 5-8. Sharpness Transfer Function for Image Quality Metric

$f_3(SVR)$ is ratio of signal to variability, a non-linear function approximating the recognition response of humans.

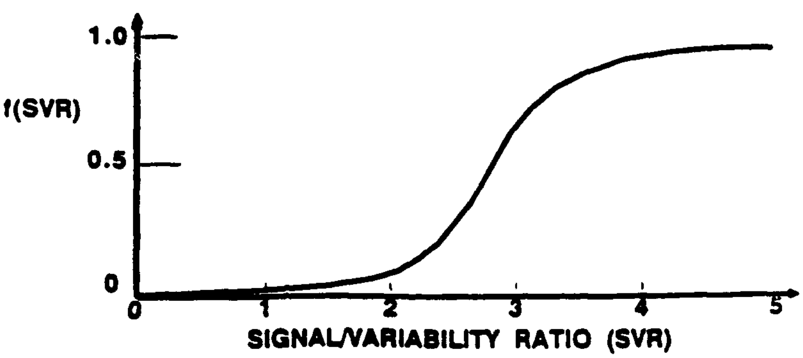


Figure 5-9. Variability Transfer Function for Image Quality Metric

5.10.3 Test Conditions

A. Weather Conditions

B. Airport Surfaces

C. Day/Night

D. Display Used

5.10.4 Report Content

Since this parameter is a computational combination of contrast, sharpness, and variability; the plots shown for them in previous sections would be repeated for the Image Quality metric. Confidence in the individual parameters and the combined image quality metric will be obtained by assessing the correlation of human recognition of the runway and/or performance.

5.10.5 Data Elements

In addition to the elements stated in Section 5.2, the following are required:

A. Video measurement of the combined raster / stroke / outside scene image that the pilot observes when looking through the Head Up Display. This must be observed by the video camera (instead of recording input video) so that image quality degradation caused by outside scene brightness can be measured.

B. Video measurement of the combined raster / stroke image sent to the cockpit Head Down Display.

5.10.6 Rationale

Synthetic vision is posing new problems for the measurement of image quality and the data gathered is expected to be somewhat unique in the public domain. If good correlations do exist, the metric will be very valuable in predicting levels of performance versus image quality, especially if used in efforts involving more and different sensors.

The effort to record the actual pilot viewing scene through the HUD is the only way in which his image quality can be reasonably established due to the tremendous effect that the outside brightness has on the ability to recognize grey scales in, or even see, the HUD raster image. It is expected that the implementation will use a small periscope which allows the camera to view the scene without excessive disturbance of the pilot's view.

6. Test Conditions

This section defines the independent experimental variables listed as test conditions in both the Operational Performance Assessment (Sections 4.3 through 4.14) and in the Experiments (Sections 5.3 through 5.10) parts of this document. A description is given of each condition, the values to be tested are listed along with the rationale for their selection. Both the conditions and their individual value selections are arranged by descending priority.

6.1 Visibility

The effects of the following visibilities, expressed in Touchdown Runway Visual Range (RVR), will be studied.

VISIBILITY
(Prioritized Order)

<700 RVR
700 RVR to 1100 RVR
1200 RVR to 1700 RVR
1800 RVR to 3 Statute Miles
>3 Statute Miles

For <700 RVR, the lowest available visibility has the highest priority (assuming the system has been judged safe for such operations).

Rationale: The primary purpose of the synthetic vision concept is to increase the pilot's effective visibility so he can perform the flight task in a normal visual manner while actually operating in low visibility. This makes the testing of the functional prototype SVS in low visibility conditions the highest priority of the investigation.

The use of RVR indicates an instrumentally derived value, based on standard calibrations, that represents the horizontal (not slant range) distance a pilot will see down the runway from the approach end. It is based on the measurement of a transmissometer made near the touchdown point of the instrument runway and is reported in hundreds of feet.

The low visibility values stop at <700 RVR in recognition that very few facilities have capability to measure below that value.

The requirements for high visibility conditions are to allow for calibration of imaging sensor performance without weather attenuation at a limited number of airports.

6.2 Weather Conditions

The effects of the following types of weather on sensor performance will be studied.

WEATHER CONDITIONS
(Prioritized Order)

Fog
Fog with Drizzle
Rain
Snow/Blowing Snow
Clear

Rationale: The types of weather being encountered will be a major determinent in how well each type of sensor performs. Weather conditions chosen are based on the characterizations used by the National Weather Service for aviation forecasts.

6.3 Airport Surfaces / Surrounding Surfaces

The following airport surface and surrounding combinations will be investigated:

RUNWAY SURFACE & CONDITIONS
(Prioritized Order)

Wet Concrete Runway with Wet Grass Surrounding
Wet Asphalt Runway with Wet Grass Surrounding
Wet Grooved Concrete Runway with Wet Grass Surrounding
Wet Grooved Asphalt Runway with Wet Grass Surrounding
Dry Concrete Runway with Dry Grass Surrounding
Dry Asphalt Runway with Dry Grass Surrounding
Dry Grooved Concrete Runway with Dry Grass Surrounding
Dry Grooved Asphalt Runway with Dry Grass Surrounding

Rationale: These are the runway materials considered to be most likely encountered by synthetic vision systems during operational conditions. It is expected that some of the combinations may not have acceptable contrast ratios and will require adjustments to the scope and repetition of the test matrix.

6.4 Imaging Sensor

The SIED system has both a Forward Looking Infra-Red (FLIR) and a Millimeter Wavelength Radar (MMW) imaging sensor. This condition determines which of them is provided to the pilot as the primary data to conduct the approach.

There is considerable difference between the FLIR and MMW sensors in image quality, scene distortion, and ability to image through weather. In the SIED, the sensors will be used to get two widely varied points in the relationship between image quality and pilot performance.

IMAGING SENSOR
(Prioritized Order)

MMW
FLIR

Rationale: In the SIED aircraft each selection changes the following parameters - all of which are of interest.

SIED SENSOR SELECTION PARAMETERS				
Sensor	Image Quality	Eye Offset	Weather Penetration	Update Rate
Human Eye	Excellent	None	Poor	~10 Hz
TV	Good	~1 foot	Poor	30 Hz
FLIR	Good	~6 feet	Poor to Fair	30 Hz
MMW	Poor	~4 feet	Good	10 Hz

6.5 Runway Incursion & Obstacle Detection

This is a characterization of the synthetic vision system sensors to detect typical obstacles that are of interest during flight and ground operations. Typical runway incursions will be simulated during approach testing to see if the pilot can detect them in time to take appropriate action. The remaining obstacles will be cataloged as to their size, composition, location, and any other pertinent characteristic; and then observed with the sensor(s) to determine if the pilot can detect their presence.

RUNWAY INCURSIONS AND OBSTACLE DETECTION
(Prioritized Order)

Aircraft/Vehicle On Runway (airborne)
Runway/Taxiway Light Fixtures (airborne and ground)
Aircraft/Vehicle On Taxiway/Ramp (ground)
Targets of Opportunity (airborne)

Rationale: Ability of the sensors to detect the various types of obstacles that must be avoided or that may cause a a runway incursion in very low visibility is a major factor in the successful application of synthetic vision technology.

6.6 Glide Path Intercept Altitude

In all non-precision scenarios the Glide Path Intercept Altitude is synonymous with the Minimum Descent Altitude (MDA). Operating from this altitude, the synthetic vision system will have to provide the pilot with sufficient information to find the airport, runway, and then to capture and track a final glide path to the runway touchdown zone. The altitude at which this will occur may range from as low as 250 feet to as high as the range of the synthetic vision sensor will allow on a 3° glideslope.

This condition is not applicable when operating on precision approaches since the conventional avionics will provide for ILS/MLS glideslope capture and initial track (nominally at altitudes of 2000' above touchdown).

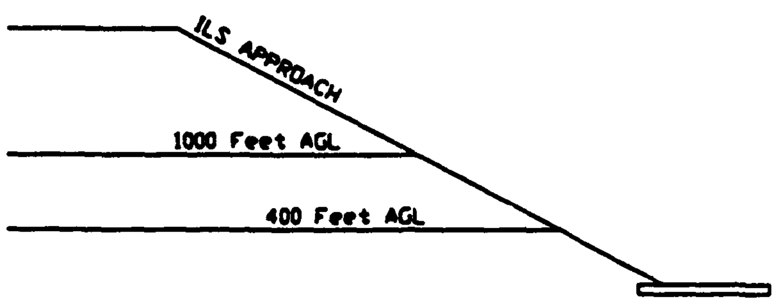


Figure 6-1. Glide Path Intercept Altitude

<u>GLIDE PATH INTERCEPT ALTITUDES</u>

1000 feet agl
400 feet agl

Rationale: The 400 foot value was chosen as a first guess of a practical minimum even though the TERPS permits values as small as 250 feet. It may be adjusted to find the minimal acceptable value.

Assuming a SVS system with a 5km range, operations at 400 feet would initially show the airport/runway at a grazing angle of 1.5° and would increase to 3° as the aircraft intercepts the nominal glide-path. The low grazing angle may create problems in initially identifying the airport/runway. This will be further compounded by the short time from glide-path intercept to flare (34 seconds at 140 kts. from the 400 foot glide-path intercept to touchdown).

The 1000 foot value was chosen to be a more favorable value to the pilot's workload, but probably straining the range of the sensor which must allow the pilot to confirm the runway at ranges greater than 20,000 feet (3.3 nmi).

TERPS minimums are summarized below:

TERPS MINIMUM ALTITUDES ALLOWED (Assuming No Obstructions)		
Approach Type	Minimum Altitude	TERPS Reference
VOR (w/ FAF); TACAN, VOR/DME (radial)	250 feet	§523a, §513.c(1)
VOR On Airport (w/o FAF)	300 feet	§413.c(1)
NDB (w/ FAF)	300 feet	§713.c(1)
NDB (w/o FAF)	350 feet	§613.c(1)
TACAN, VOR/DME (arc)	500 feet	§523.b(3)
UHF/VHF DF	500 feet	§813.c(1)

6.7 Zero/Zero Demonstration

This condition requires that performance data be taken in Zero Visibility / Zero Ceiling conditions. If Zero/Zero conditions are not possible in acutal weather, simulated IMC will be used.

<u>ZERO/ZERO TEST REQUIREMENT</u>

Required
Not Required

Rationale: Near-ground and on-ground operations need to be investigated in zero-zero conditions as well as actual "low - but not zero/zero" visibilities. Operational capability in actual weather is the priority goal for the SIED. However, zero/zero conditions conincident with the availability of a qualified aircraft may not be possible. Then the evaluation pilot will be placed in simulated zero/zero condition through the use of hoods or curtains.

6.8 ILS Guidance Cutout

When studying the effects of transitioning from an ILS to FPSVS environment, there is an altitude at which the ILS beam should be turned off or disregarded by the pilot.

<u>ILS GUIDANCE CUTOUT</u>

200 feet

Rationale: Initially the ILS data will be disregarded by the evaluation pilot at 200 feet, but it may be extended to 100 feet to reflect the general availability of reliable ILS data to this altitude. Leaving it at 200 feet is a worst case in terms of pilot workload since the pilot must be totally dependent on the SVS earlier in the approach.

6.9 Approach Offset Angle

The Approach Offset Angle simulates the position errors which may exist due to use of conventional aircraft navigation systems at the time that the SVS approach is initiated. Various offsets, measured in terms of the angle they make with the runway centerline at the nominal touchdown point are given to the pilot. Initial heading at each approach angle will be the nominal for a zero degree offset.

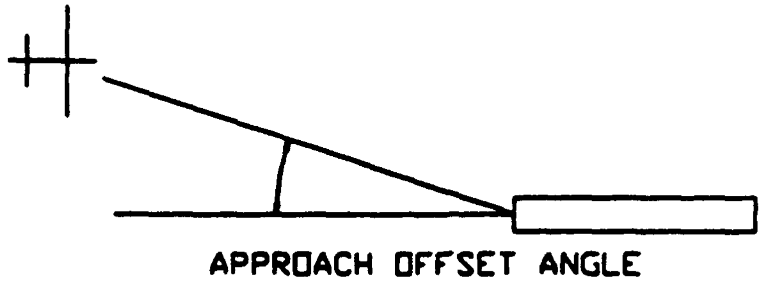


Figure 6-2. Approach Offset Angle

APPROACH ANGLE VALUES

0°
+6°
-6°

Rationale: Existing precision (ILS) approaches can be designed with as much as the six-degree error from straight-in. It is expected that any aircraft carrying a synthetic vision system will also have advanced navigation aids that will allow, at most, the same six degree final approach error on any precision, non-precision, or no-approach-aid scenario.

6.10 Display Used

The SIED aircraft has both head up and head down displays capable of displaying the SVS image. It is expected that day operations with the HUD will have degradation due to the washout of the image against the outside scene. This effect will not occur in the HDD. The use of the HDD as a compliment and/or a backup to the HUD will be investigated as well as the possibility of using only a HDD in a synthetic vision implementation.

DISPLAY SELECTION

Head Up Display (HUD)
Head Down Display (HDD)

Rationale: These are the only two displays capable of being used with the Synthetic Vision System.

6.11 Day/Night

Day/Night conditions impose significant changes to the flight environment. Daytime brightness will significantly change the number of grey-scale tones which can be observed on the Head Up Display. Night environments significantly change the perception of real world outside cues provided to the pilot's natural vision as well as reducing his depth perception.

DAY / NIGHT CONDITIONS

Day
Night

Rationale: Advertised specs on HUD raster indicate that 8 grey scales are available with an outside scene brightness of 50 ft.-lamberts. When the brightness is between 5,000 - 10,000 ft.-lamberts on a typical day, the ability to see grey intensities will significantly decrease. Note that this grey scale limitation is most evident when operating in IMC during the day due to the "white out" viewed through the window. Also, when allowing the pilot to operate with combined natural

and synthetic vision, the effects on depth perception and orientation are expected to be significant.

6.12 Crosswinds

Operations in crosswinds complicate the pilot's landing task and also reduce the effective view around the downwind side of the runway by the amount of the required crab angle. The SIED is not expecting crosswind conditions to be a major determinant in the SVS's success, but will sample performance in cross-winds during the performance and/or weather matrices.

GROUND CROSSWIND VALUES
(Maximum 90° Component)

11 - 15 Kts

Rationale: The G-II aircraft is certificated for 20 kts of 90° crosswind component, but Part 135 operations are limited to the 15 knot maximum shown.

6.13 Flare Guidance Cue

The Flare Guidance Cue provides the pilot with an avionics driven guidance symbol that the pilot will follow to control the descent rate to an acceptable amount at touchdown. It makes no attempt to attain touchdown at any given point or airspeed. The technology is well proven and is expected to fully compensate the pilot for the SVS image quality, sensor offset from the design eye, and lack of stereo vision.

FLARE GUIDANCE CUE

On
Off

Rationale: The flare guidance cue is expected to exist on any aircraft using Synthetic Vision. It is being turned off in this test matrix only when the pilot's workload under different sensors or image processing is being evaluated and the cue would get in the way of seeing the results of the image quality changes on performance.

7. FLIGHT OPERATIONS REQUIREMENTS

7.1 Operational Assessment/Experiment Priorities

The experimental design process has resulted in the establishment of the following test priorities:

- Priority 1
  - — Visibility
  - — Weather Conditions
  - — Airport Surfaces
  - — Sensor Used
- Priority 2
  - — Runway Incursions
  - — Glide Path Intercept Altitude
  - — Zero / Zero Demonstration
  - — ILS Guidance Cut-Out
  - — Approach Offset Angle
- Priority 3
  - — Display Used
  - — Day / Night
  - — Crosswinds
  - — Flare Guidance Cue

7.2 MMW Radar Calibration Flights

Each of four reference runways are to be calibrated to support the MMW radar experiments. Calibration requirements include:

- Deployment of Corner Reflectors along runway
- Approach conducted in clear weather with the corner reflectors and runway in the radar field of view.
- Identification of secondary calibration references which are permanently placed and within the radar field of view.

7.3 FLIR Calibration

There is no requirement to calibrate the FLIR sensor against field targets.

8. DATA REPORTING/ANALYSIS REQUIREMENTS

This section presents the type of products required for graphical analysis and inclusion in the final report. The types and format of graphical presentation are presented in sufficient detail to establish the requirements for data reduction software tools. The data elements shown in the graphics should only be considered as representative; the final choice of data elements will be made during the analysis of flight data.

8.0.1 Pilot Evaluation of Capability

Pilot evaluation of capability will be by use of the Cooper-Harper rating system for handling qualities and a modified version for workload. These will be supplemented by written narratives. Ratings will be plotted against the independent conditions listed for each issue in Section 4 and described in detail in Section 6. Typical examples are shown in Figure 8-1.

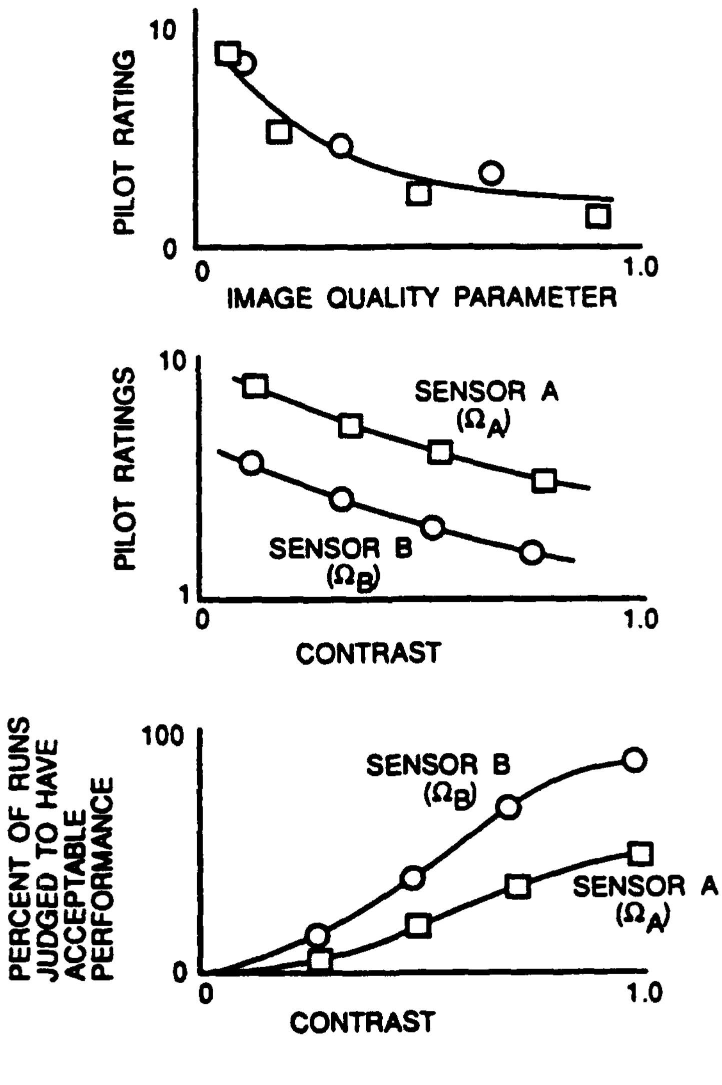


Figure 8-1. Pilot Subjective Ratings versus Conditions (Sample)

Additional correlations of pilot evaluations with image quality measurements will be made. Examples are shown in Figure 8-2.

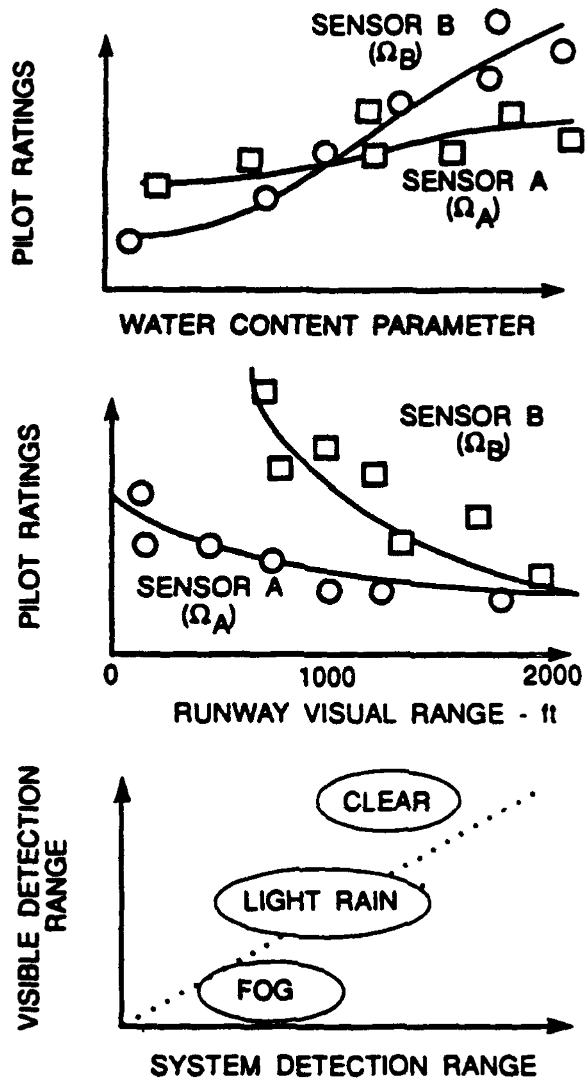


Figure 8-2. Pilot Subjective Ratings versus Image Quality Parameters (Sample)

8.0.2 Plan and Profile Views of Track or Trajectory

The analysis of aircraft motion towards the runway and the relative points where pilot detection of the airport and runway will use a projection of aircraft's motion into a plan and/or profile view. Specific occurances are plotted on top of the aircraft's track history. Figure 8-3 shows the expected format.

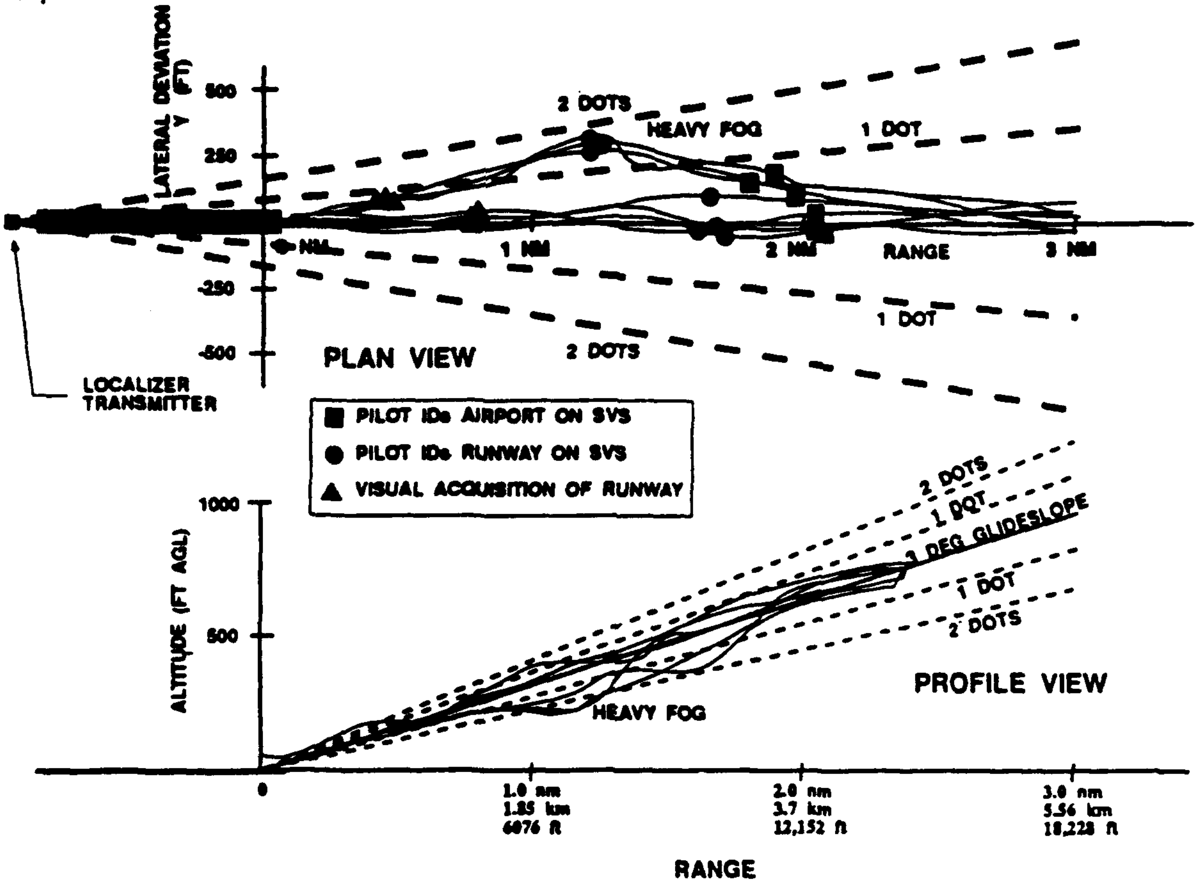


Figure 8-3. Plan and Profile View Of Achieved Performance (Sample)

8.0.3 Aircraft Parameters As A Function Of Range

Aircraft heading, attitude (pitch, roll), airspeed, and other parameters may be plotted to the same range scale as the Plan/Profile View and shown below them as required to illustrate a problem. This will also be done for typical computational terms that may be used such as standard

deviations, averages, probability of detection, or error plots.

8.0.4 Hodograph of Altitude versus Altitude Rate

This x-y plot format is used to interpret how well a flare maneuver is performed. Figure 8-4 provides an example.

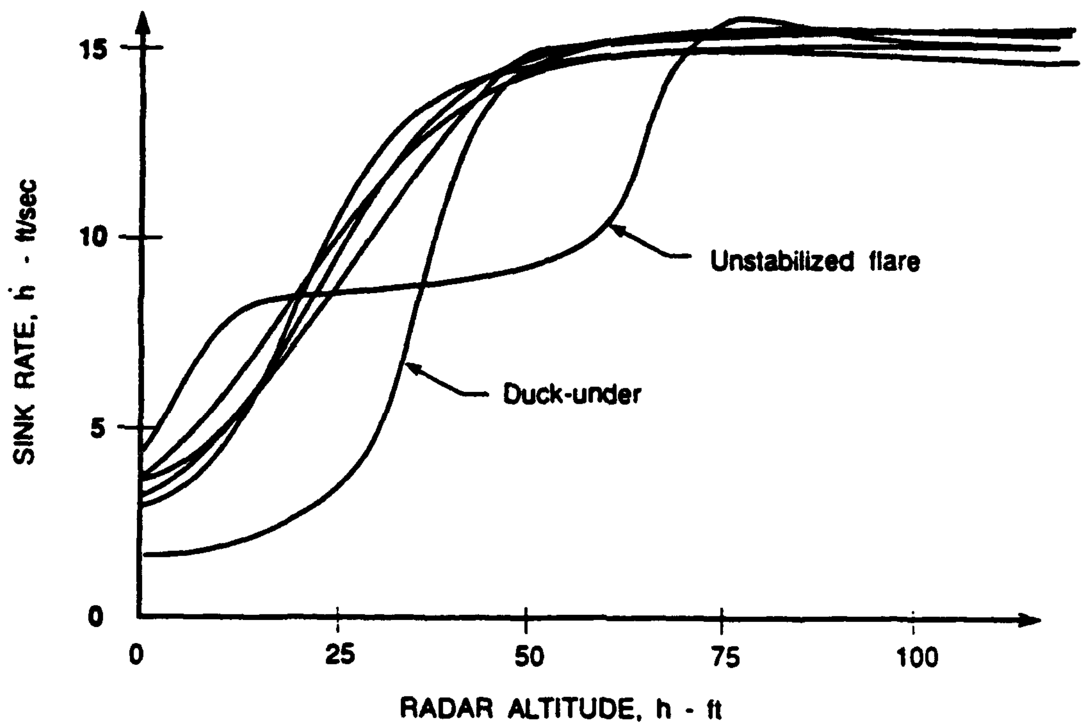


Figure 8-4. Hodograph of Altitude versus Altitude Rate (Sample)

8.0.5 Landing Position (Longitudinal and Lateral) and Sink Rate

A combination plot that allows the observer to quickly assess the touchdown performance in terms of lateral, longitudinal, and vertical velocity is shown in Figure 8-5. Notice that it allows a number of landings to be presented at the same time with minimal data loss to the viewer:

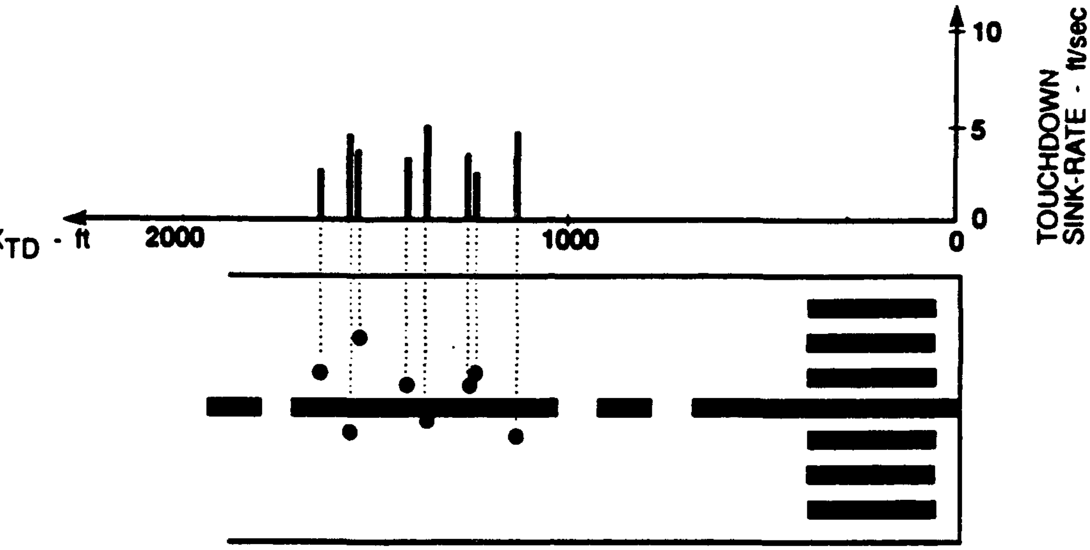


Figure 8-5. Landing Performance (Sample)

8.0.6 Radar Reflectivity

The reflectivity of the airport surfaces and surrounding terrains will be correlated against variables of interest. A typical example may be correlation of various surface reflectivities with differing depression angles as shown in Figure 8-6.

Plot of average normalized RCS versus depression angle for wet and dry grass

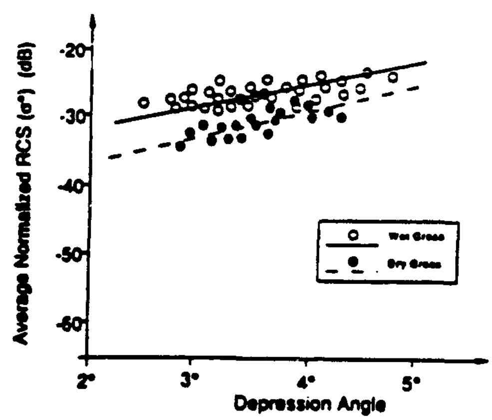


Figure 8-6. Surface Radar Reflectivity versus Depression Angle (Sample)

8.0.7 Path Attenuation

Attenuation will be correlated to conditions found to be of interest as well as models. An example is Figure 8-7.

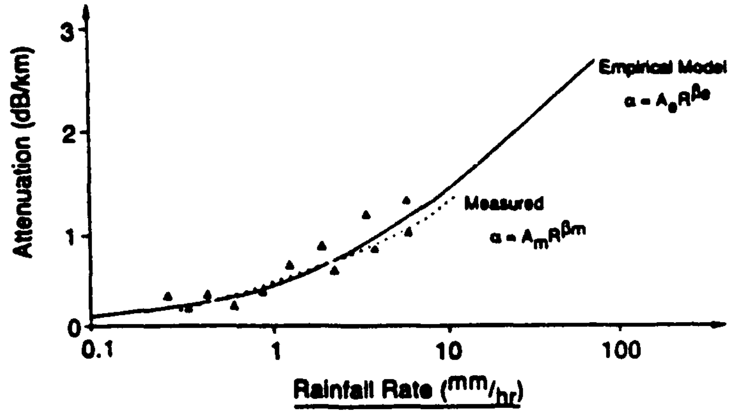


Figure 8-7. Attenuation versus Rainfall Rate (Sample)

8.0.8 Backscatter

Backscatter will be correlated to conditions found to be of interest as well as models. Typical presentation may follow Figure 8-8.

OTHER INDEPENDENT VARIABLES
(WEATHER METRICS)

- Liquid Water Content (g/m^3) for Fog
- Equivalent Rainfall Rate ($^{mm}/_{hr}$) for Snow

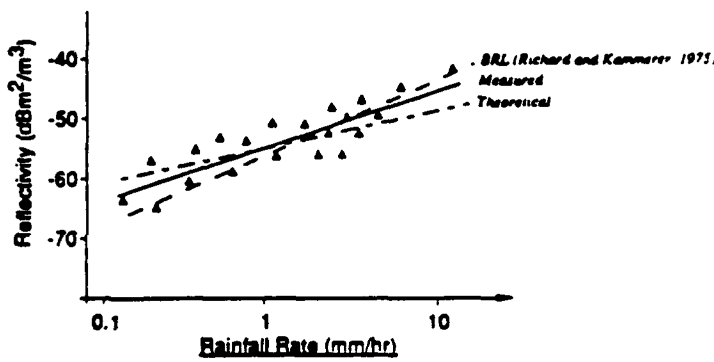
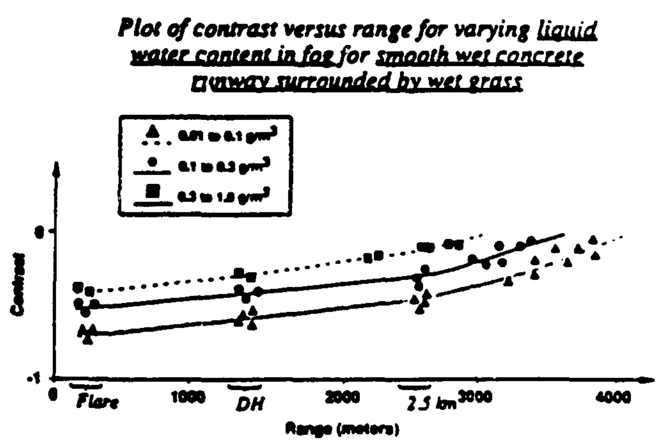


Figure 8-8. Rain Reflectivity (Volumetric Backscatter) versus Rainfall Rate (Sample)

8.0.9 Scene Contrast

Contrast data will be presented as a correlating factor in many of the other performance and experiment reports. Multiple plots may be made to show differing correlations with the test conditions. Examples include Figures 8-9, 8-10, and 8-11.

1. Contrast versus range to target:



POSSIBLE COMBINATIONS
(Test Matrix)

Weather
- Rainfall Rate (rain)
- Equivalent Rainfall Rate (snow)

Runway/Terrain Description
- Smooth Dry Concrete/Dry Dirt
- Grooved Wet Concrete/Wet Chaparral
- Smooth Wet Asphalt/Wet Grass
- Snow on Asphalt/Snow on Grass

Figure 8-9. Contrast versus Range (Sample)

2. Contrast versus Rainfall Rate:

Plot of contrast versus rainfall rate in rain for smooth wet asphalt runway surrounded by wet chaparral for specific ranges.

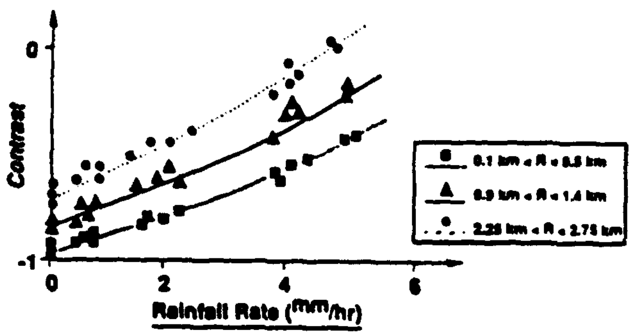
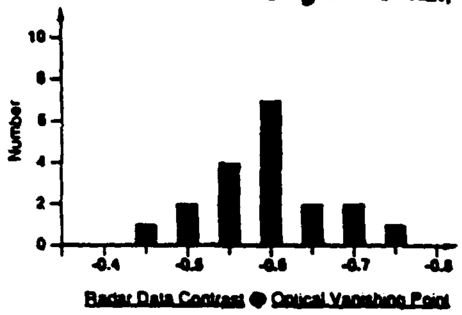


Figure 8-10. Contrast versus Rainfall Rate (Sample)

3. Raw Radar Data Contrast in a histogram format, determined at Optical Vanishing Point:



- ***Other Dependent Variables***
  Radar Data Sharpness
  Radar Data Variability
- ***Other Analysis Point***
  Radar Vanishing Point

Note: Segregation by specific airport or airport type (to highlight effects of external cues) is desirable provided sufficient data quantities are available

Figure 8-11. Histogram of Raw Radar Data Contrast at Optical Vanishing Point (Sample)

8.0.10 Edge Sharpness

Sharpness data from this experiment will be presented as a correlating factor in many of the other performance and experiment reports. Multiple plots may be made to show differing correlations with the test conditions. Examples include Figure 8-12 and 8-13.

1. Sharpness versus range to target:

Plot of sharpness versus range for moderate rainfall rates for smooth wet asphalt runway surrounded by wet chaparral

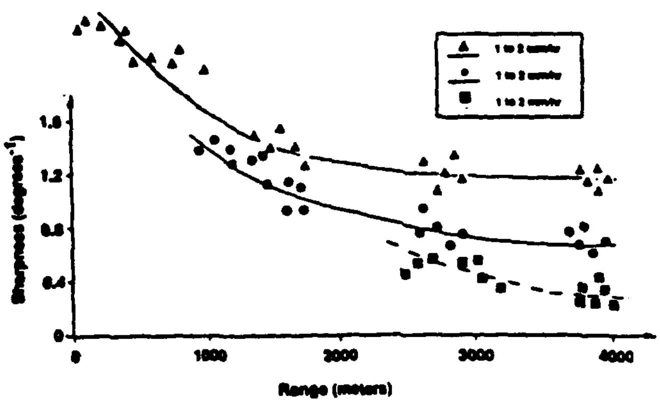


Figure 8-12. Sharpness versus Range (Sample)

2. Sharpness versus Fog Liquid Water Content:

Plot of sharpness versus liquid water content in fog for smooth dry concrete runway surrounded by dry grass for specific ranges

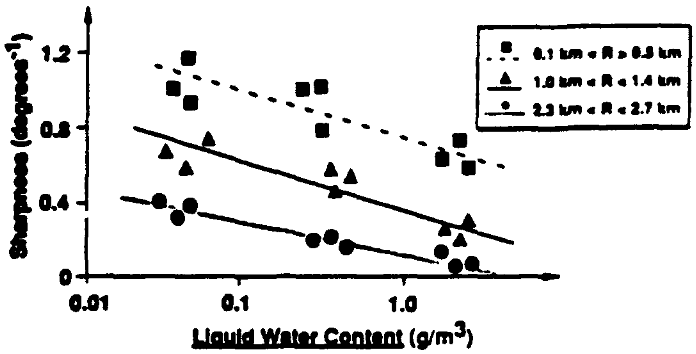


Figure 8-13. Sharpness versus Fog Liquid Water Content (Sample)

8.0.11 Variability

Variability data from this experiment will be primarily used in generation of image quality figures of merit. Correlations with typical parameters such as surfaces, weather, or range will be shown as they are found to be meaningful.

8.0.12 Image Quality Metric

Since this parameter is a computational combination of contrast, sharpness, and variability; the plots shown for them in previous sections would be repeated for the Image Quality metric. Confidence in the individual parameters and the combined image quality metric will be obtained by assessing the correlation of human recognition of the runway and/or performance.

9. DATA ELEMENT AND SOURCE REQUIREMENTS

The following table describes the data elements required to support the SIED analysis efforts. The source for each data element is also provided.

DATA ELEMENT AND SOURCE REQUIREMENTS			
Data Element	**Source**	**Interface**	**Update Rate**
Present Position	LTN-92 INS	ARINC 429	125 msec
Present Position	UNS-Jr GPS	ARINC 429	125 msec
N-E Velocity	LTN-92 INS	ARINC 429	62.5 msec
Body Axis Accelerations	LTN-92	ARINC 429	15.6 msec
Body Axis Rotation Rate	LTN-92	ARINC 429	15.6 msec
Track Angle, True	LTN-92	ARINC 429	31.3 msec
Baro Corrected Altitude	DADC	ARINC 429	62.5 msec
Altitude Rate	DADC	ARINC 429	62.5 msec
True Airspeed	DADC	ARINC 429	125 msec
Total Air Temp	DADC	ARINC 429	500 msec
Static Air Temp	DADC	ARINC 429	500 msec
Baro Correction (Hg)	DADC	ARINC 429	125 msec
Ambiant Light Brightness	HUD	ARINC 429	100 msec
Symbol Brightness	HUD	ARINC 429	100 msec
Video Brightness	HUD	ARINC 429	100 msec
Video Contrast	HUD	ARINC 429	100 msec
Distance To Fix	DME	Analog	125 msec
Valid Data Flag	DME	Discrete	500 msec
ILS Deviation	NAV Receiver	Analog	62.5 msec
LOC Deviation	NAV Receiver	Analog	62.5 msec
Enabled/Valid	NAV Receiver	Analog	500 msec
Radar Altitude	Radar Altimeter	Analog	62.5 msec
Valid	Radar Altimeter	Discrete	62.5 msec
Weight On Wheels	Squat Switch	Discrete	62.5 msec
Pitch/Roll Commands	Control Yoke	Analog	62.5 msec
Time	IRIG Time Code Generator	Discretes	15.6 msec
Event Markers	Pushbuttons	Discretes	62.5 msec
Weather Condition	JTD System	RS-232	1000 msec
MMW Sensor Video	Sensor Vendor	Analog RS-170	N-A
FLIR Sensor Video	Sensor Vendor	Analog RS-170	N-A
HUD Video		Analog RS-170	N-A
Radar Raw Data	Radar System	Sensor Vendor	PCM to Instr. Rcdr
Pilot View Camera	Sensor Vendor	Analog RS-170	N-A
Cockpit Voice		Analog	N-A

Figure 9-1. Data Elements And Sources

10. FAA SVSTD Coordination

The TRW SIED Program has taken steps to assure that the data acquired will form a consistent data set with other elements of the FAA SVSTD Project. The specific steps taken include:

A. Definition of Terms: The forms of defining equations and terms for variables have been coordinated with the sensor manufacturers, USAF Tower test data reduction personnel, and the SVSTD Project consultants.

B. Measurement Methodology: All measurements have been coordinated throughout the SVSTD Project members so that results will not differ substantially due to measurement techniques.

C. Proprietary Data: Georgia Tech Research Institute will process and prepare the proprietary data report detailing the radar sensor. Their evaluation and report of the TRW SIED flight data will be compatible with their USAF contracted report on the same sensor's *Tower Test* performance.

D. Coordination: TRW has established and maintains contractual access to all principals needed to assure that SVSTD Project elements remain informed and coordinated.

APPENDIX B

MAJOR CHARACTERISTICS OF TESTED SENSORS

Honeywell 35 GHz Imaging Radar

Lear Astronics 94 GHz Imaging Radar

Kodak 3-5 Micron Infrared Camera

MAJOR CHARACTERISTICS OF THE 35 GHz RADAR SENSOR

1.0 FLIGHT TEST CONFIGURATION

Figure B-1 shows a function block diagram of the flight test configuration of the 35GHz SVS sensor provided by the Honeywell Systems Research Center. Image enhancement functions within the display processor were only implemented experimentally, and were not part of the baseline flight test configuration.

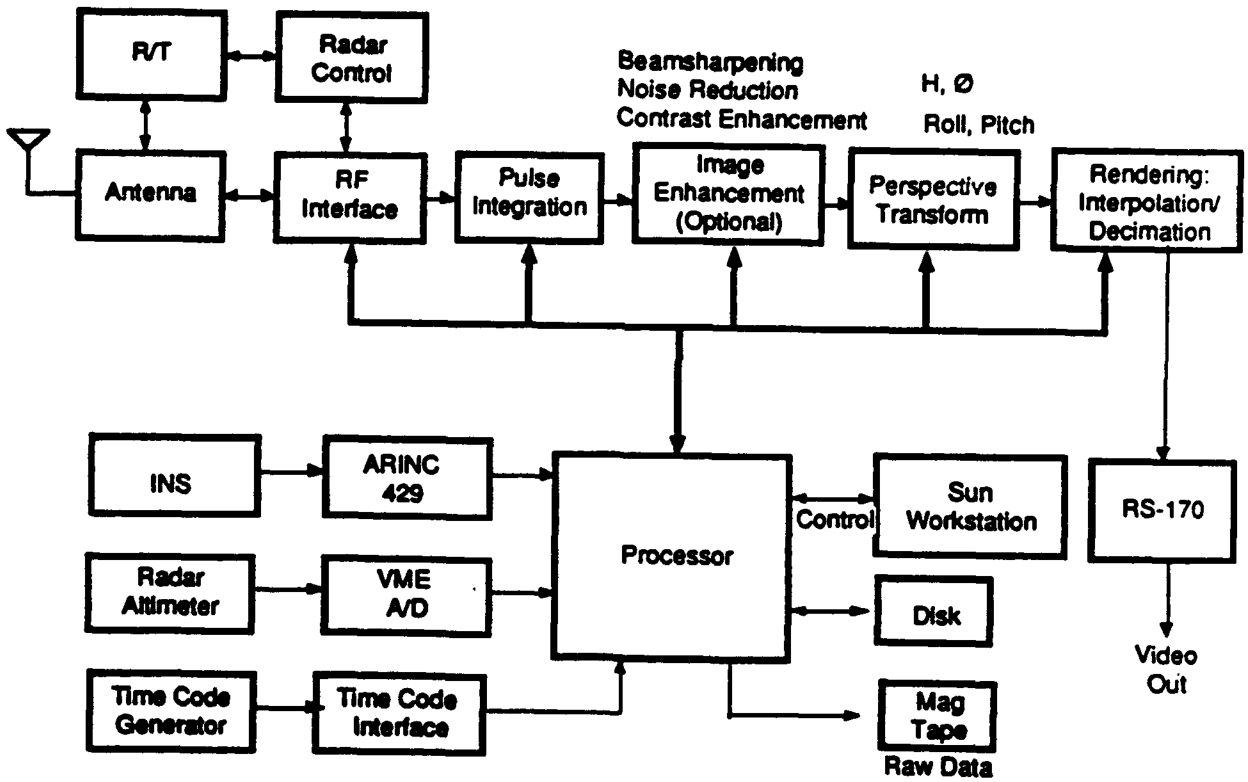


Figure B-1 Honeywell 35 GHz Imaging Radar Block Diagram

The antenna developed for the 35 GHz sensor by Malibu Research Inc. is a strap down electro-mechanical scanner based upon an "Eagle Scanner" technique. Using a dielectric slug to change the phase velocity of a waveguide feed, the antenna scan rate was configured at approximately 10 Hz for flight testing. A shaped reflector with a horizontal aperture of 30 inches is used to achieve a vertical fan-beam pattern of approximately 26 degrees (6 degrees at 3 dB down) with cosecant squared rolloff, and an azimuthal beamwidth of 0.8 degrees.

The transmitter is a conventional magnetron based pulsed transmitter at 35 GHz. It transmits an average power of 1.0 watt. The receiver consists of a MMIC low-noise amplifier (LNA), a mixer, and an intermediate frequency circuit. The transmitter and receiver are housed in separate structures and are controlled by a modulator within the R/T Controller, and an RF interface board within a separate display processor chassis.

The display processor, mounted in the aircraft cabin, consists primarily of industry TMS320C30- based DSP boards in a ruggedized Versa Module Eurocard chassis. Multiple (18) TMS320C30 processors are used to perform pulse integration, optional image enhancement, perspective transform and display interface functions. The most intensive processing is the perspective transform from the B-scope radar image to the pilot perspective image. The display processor also contains commercially available ARINC bus interface and data input/output cards from which aircraft orientation parameters are extracted for input to the perspective transform.

A Sun workstation was also mounted in the aircraft cabin and served as a station for software development, user control of operating parameters, and data recording. Raw digital radar signal data, captured by the Radar Interface card, is first transferred through a series of two disk drives. The raw data is finally recorded onto high density magnetic tape under control of the Sun workstation.

2.0 SYSTEM ISSUES AND REVISIONS

Honeywell addressed the following issues through the course of flight testing on a basis that neither interfered with flight testing nor invalidated collected sensor data.

2.1 ROLL LATENCY

Display update latency appeared to be on the order of 0.4 seconds during periods of high roll angle rate. Investigation of the problem revealed that one software subroutine had not been executing fast enough to keep up with incoming data. The particular subroutine was responsible for updating the INS reference data structures. Unsuccessful efforts were made to optimize this subroutine, and the latency problem remained through the program.

2.2 ANTENNA PITCH

Several tests were performed to evaluate overall sensor performance at varying antenna pitch angles. Tests that traded off antenna pitch angles optimized for taxi versus landing approach concluded that an antenna pitch stabilization mechanism would be desirable in future imaging systems. For the purpose of completing the flight tests, the antenna pitch angle was set as reflected in Figure B-2.

2.3 RUNWAY "PHANTOMS"

Flight tests revealed a runway "phantom" phenomenon, exhibited as transient cloudy returns in the radar image which moved across the runway in an irregular but non-random pattern at the lower altitudes of the aircraft approach to the runway and during the landing rollout. Approaches without use of weather and altimeter radar transmitters proved that the effect was not caused by interference from these sensors. Some observers suggested that the artifacts might be associated with runway/taxiway markers and/or runway distance remaining signs. Absorptive material was placed inside the radome to mitigate the effects of potential sidelobe returns with no effect. The problem was not resolved during flight testing, however radar multipath or processing artifacts remain as candidate causes. While noticeable to the pilots, the pilots did not feel that these anomalous returns affected their use of the image during the flight tests.

2.4 120 MHz RFI

Emissions from the imaging radar partially interfered with aircraft communications radios in the 120 MHz range. The problem was not resolved during flight testing.

2.5 DIAGONAL DISPLAY WAVES

Diagonal waves appeared on the display due to the fact that display memory was updated vertically and the display raster operated horizontally and asynchronously. Several solutions were traded off, with the solution requiring the least processor throughput being selected. Synchronization of the display memory update with the display raster readout froze the diagonal line in the display. The frozen line was substantially less distracting than the traveling wave initially exhibited and deemed acceptable by the pilots for flight test purposes.

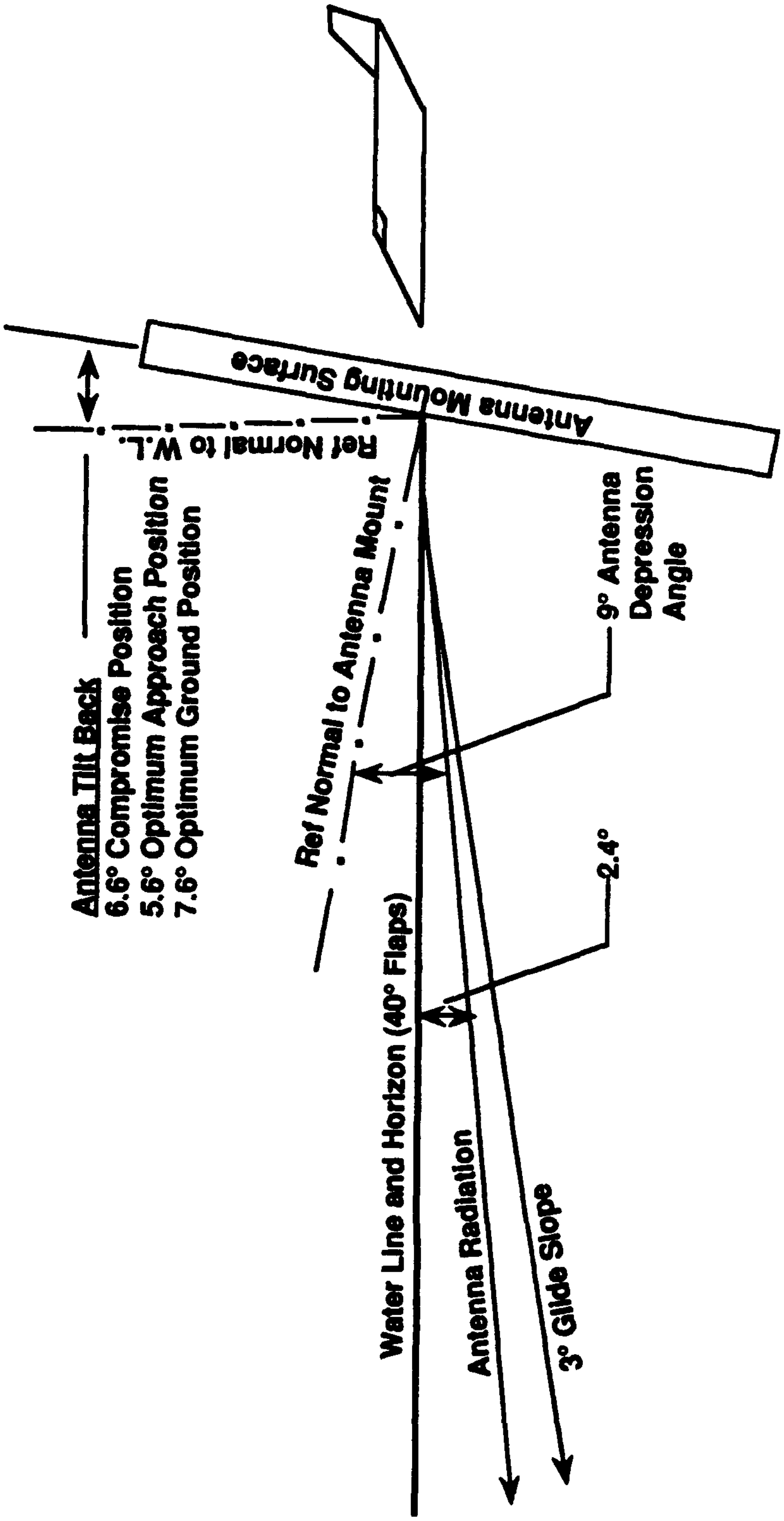


Figure B-2 35 GHz SVS Antenna Pitch Angle for Flight Test

2.6 DATA RECORDING SUSPEND

The data recording process required software modification to allow the process to be suspended for system power down. This capability was added, allowing the recording process to be resumed without loss of data, subsequent to cycling system power.

2.7 IMAGE ENHANCEMENT

Honeywell attempted to demonstrate software functions for enhancing the radar image, including beam sharpening, contrast enhancement and noise reduction routines. Initial problems were incurred in integrating the routines for real time operation. The routines did execute during one flight test with poor results. A problem involving dynamic update to a coefficient table precluded successful demonstration of image enhancement software.

MAJOR CHARACTERISTICS OF THE 94 GHz RADAR SENSOR

1.0 FLIGHT TEST CONFIGURATION

Figure B-3 shows the major functions of the Lear Astronics 94 GHz sensor developed for the SVS Technology Demonstration Program.

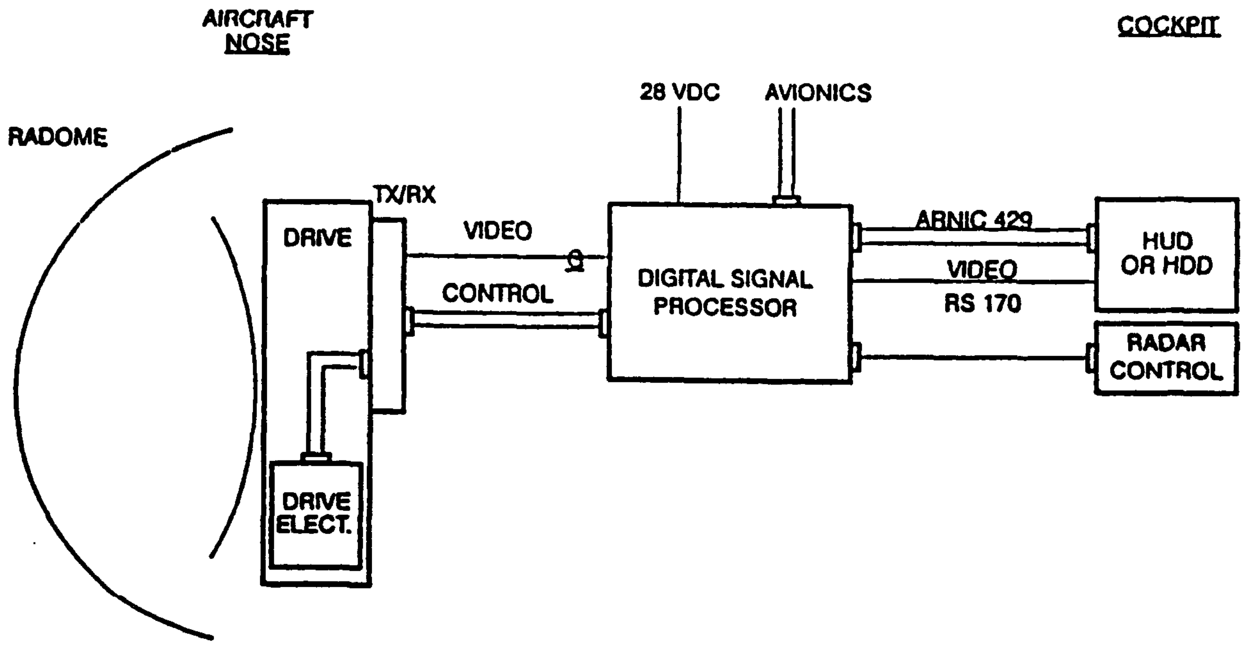


Figure 3. Lear Astronics 94 GHz SVS Sensor System Configuration

The sensor system consisted of a 94 GHz scanning antenna , a transmitter/receiver, a radar interface unit, a digital signal/image processor, and an integral data collection system. The antenna with its drive electronics, the transmitter/receiver, and the radar interface unit were mounted in the radome of the test aircraft. The Digital Signal Processor and data recording equipment were installed in the cabin of the aircraft.

The 24inch by 8 inch Flat Parabolic Surfaces (FLAPS) scanning reflector antenna was developed by Malibu Research Inc. for the SVS program. The feed is fixed and only the reflector scans ±7.5 degrees. The antenna produces a 2:1 enhancement, which provides a ±15 degree field of view. The FLAPS surface focuses the beam, converts from linear to circular polarization, and forms the cosecant squared elevation shaped beam. The antenna is scanned at 5 Hz in azimuth and is pitch stabilized under computer control from the engineers test station in the cabin.

The 94 GHz solid state Frequency Modulated Continuous Wave (FMCW) linearized transceiver developed by GEC-Marconi Dynamics is mounted integrally to the antenna assembly behind the reflector surfaces to minimize waveguide losses. The radar transmitter uses a phase lock loop linearized Voltage Controlled Oscillator and an Injection Locked Oscillator to produce 250 mW output power. The receive signal is down converted to baseband and then amplified by a digitally gain controlled amplifier stage to produce the frequency/range related signal. The conversion from frequency to range is performed in the system Digital Signal Processor.

The Digital Signal Processing (DSP) unit consists of a Fast Fourier Transfer (FFT) card (400 μsec conversion time), a scan converter, and six RISC architecture MIPS R3000 processor/memory card pairs in a single chassis. The DSP's primary function is to process a radar return signal and convert it to a displayable image of the runway scene. The radar return input is digitized and stepped through an FFT calculation, creating 256 range profiles per scene, each consisting of 512 range bins. Each range profile is processed individually to enhance the scene definition. Scenes are processed at a rate of 10 per second. The standard radar B scope out (range versus azimuth) is converted, in real time, to a C scope presentation (elevation versus azimuth). After processing, the range profiles are collected in the scene memory space of the scan converter. Motion compensation of the scene for changes in aircraft attitude are performed before data conversion to RS-170 output format.

2.0 OPERATIONAL SPECIFICATIONS

A summary of the operational specifications of the Lear Astronics 94 GHz SVS sensor is shown in Table B-1. The extent to which the specifications were met was not fully established.

Table B-1 94 GHz SVS Sensor Operational Specifications

OPERATIONAL SPECIFICATIONS	
Maximum Range	6,000 meters - Acquisition mode 3,000 meters - Approach mode 1,500 meters - taxi mode
Mode Change	Automatic and manual
Azimuth Resolution	0.35 degree (5.4 milliradian) (Two way antenna azimuth beamwidth)
Range Resolution	14 meters - acquisition mode 7 meters - approach mode 3.5 meters - taxi mode

MAJOR OPERATING CHARACTERISTICS OF THE KODAK KIR 310 INFRARED SENSOR

Aperture Diameter (mm)	36 mm, f1.6
Operating Wavelength (μ)	3-5 μm
Field of View (deg x deg)	32° (AZ) x 24° (EL)
Array Dimension (pixels)	640 x 486
NEΔT (K)	0.15 K
Minimum Resolvable Temp	0.1 K at 1/2 Nyquist (0.01K at low frequencies)
Quantum Efficiency (%)	.05% at 4 μm

APPENDIX C

Major Operating Characteristics of the GEC Head-Up Display

Instantaneous Field of View	30° (AZ) x 16.5° (EL)	
Total Field of View	30° (AZ) x 24° (EL)	
Intensity	400 Foot-Lamberts	
Video Inputs	two EIA RS-170 (MMW and FLIR)	
Video Outputs	two EIA RS-170 (DAS and HDD)	
Video Selection Input	TTL (MMW or FLIR)	
Test Data Outputs	ARINC-429 (Ambient Light Level & Control Settings)	
Symbol Set	Modified FAA Symbol set #1	
Aircraft Inputs	INS #1	ARINC-429
	INS #2	ARINC-429
	ADC	ARINC-429
	DME #1	Analog/Discrete
	DME #2	Analog/Discrete
	VHF Nav #1	Analog/Discrete
	VHF Nav #2	Analog/Discrete
	Radar Altimeter	Analog/Discrete
	Weight On Wheels	Discrete
Pilot Control Panel	On/Off	
	Desired Glide Slope	
	Desired Airspeed	
	Heading	
	HUD Contrast	
	HUD Intensity	
	HDD Intensity	

APPENDIX D.

OVERVIEW OF DATA ACQUISITION SYSTEM
AND
DATA SOURCES

- **Flight Test Engineer's Event Log Format**
- **Data Acquisition System Overview**
- **Data Source Responsibilities**
- **SVS Performance Analyses Responsibilities**
  - System Level - TRW
  - Sensor Level - GTRI
  - Meteorological - JTD

FLIGHT TEST ENGINEER'S EVENT LOG FORM

Experiment Number

SVSTD

Run	Airport	Runway	Pilot
A			
B			
C			
D			
E			
F			

Ask for ATIS

Time			
Airport			
Tops			
Ceiling			
Visibility			
Temperature			
Winds			
Direction			
Baro			

A

	Take-Off	Approach	Touchdown
VCR Counter			

FG Time

Type

HUD	Sensor	Comments
	FLIR	
	Wind	
	MMW	

B

	Take-Off	Approach	Touchdown
VCR Counter			

FG Time

Type

HUD	Sensor	Comments
	FLIR	
	Wind	
	MMW	

C

	Take-Off	Approach	Touchdown
VCR Counter			

FG Time

Type

HUD	Sensor	Comments
	FLIR	
	Wind	
	MMW	

D

	Take-Off	Approach	Touchdown
VCR Counter			

FG Time

Type

HUD	Sensor	Comments
	FLIR	
	Wind	
	MMW	

E

	Take-Off	Approach	Touchdown
VCR Counter			

FG Time

Type

HUD	Sensor	Comments
	FLIR	
	Wind	
	MMW	

F

	Take-Off	Approach	Touchdown
VCR Counter			

FG Time

Type

HUD	Sensor	Comments
	FLIR	
	Wind	
	MMW	

FS=Full Stop
TG=Touch & Go
MA=Missed Approach

DATA ACQUISITION SYSTEM OVERVIEW

		Primary Sensor			Backup Sensor		
Data Source	**Type**	**TRW**	**JTD**	**Hny**	**TRW**	**JTD**	**Lear**
MMW image	RS-170	√		X	√		X
FLIR image	RS-170	√			√		
HUD image	RS-170	√			√		
Combiner Camera	RS-170	√		X	√		X
MMW Internal Data	Digital			X			X
Radar Altimeter	Analog	√		X	√		X
INS	ARINC-429	√		X	√		X
DADC	ARINC-429	√		X	√		X
GPS	ARINC-429	√			√		
HUD (Ambient Light)	ARINC-429	√			√		
VHF Navigation	Analog	√			√		
DME	Analog	√			√		
Yoke Position	Analog	√			√		
particle size (fog)	Digital		*			*	
particle size (rain)	Digital		*			*	
liquid water content	Digital		*			*	
Altitude	Analog		*			*	
Airspeed	Analog		*			*	
True Air Temperature	Analog		*			*	
Weather Summary	RS-232	√			√		
Intercom	Analog	√			√		
SVS configuration	Files	√			√		
Experiment notes	Files	√			√		
IRIG-B Time Tag	Analog / Digital	√		X	√		X
Time (1 sec resolution)	Digital		*			*	

√ data was processed by TRW for System Level Analysis
X data was processed by GTRI (and MMW Vendor) for Sensor Level Analysis
* data was processed by JTD and distributed to TRW, GTRI, and MMW Vendor

DATA SOURCES AND ELEMENTS (TRW)

Source	Type	Data Rate	Recorder	Elements
INS #1	ARINC 429	100 Kbps	8 mm (digital)	Desired Track
				Cross Track
				Pres Pos - Lat
				Pres Pos - Long
				Ground Speed
				Track Angle True
				True Heading
				Wind Speed
				Wind Direct True
				Track Angle Mag
				Mag Heading
				Drift Angle
				Flight Path Angle
				Flight Path Accel
				Pitch Angle
				Roll Angle
				Body Pitch Rate
				Body Roll Rate
				Body Yaw Rate
				Body Longitude Accel
				Body Lateral Accel
				Body Normal Accel
				Platform Heading
				Track Angle Rate
				Pitch Att Rate
				Roll Att Rate
				Potential Vert Speed
				Inertial Altitude
				Along Trk Horiz Accel

DATA SOURCES AND ELEMENTS (TRW) (CONTINUED).

Source	Type	Data Rate	Recorder	Elements
				Cross Trk Horiz Accel
				Vertical Accel
				Inertial Vert Speed
				N-S Velocity
				E-W Velocity
ADC	ARINC 429	13.9 Kbps	8 mm (digital)	Pressure Altitude
				Baro Corrected Alt.
				Mach Number
				Indicated Airspeed
				V_{mo}
				True Airspeed
				Total Air Temperature
				Altitude Rate
				Static Air Temperature
				Baro Correction
				Baro Correction
GPS	ARINC 429	13.9 Kbps	8 mm (digital)	Altitude
				Latitude (Coarse)
				Longitude (Coarse)
				Latitude (Fine)
				Longitude (Fine)
				Measurement Age
				GPS Status
				RPU Status
HUD	ARINC 429	100 Kbps	8 mm (digital)	Ambient Light
				Symbol Brightness
				Video Brightness
				Video Contrast
RA	Analog/Discrete		8 mm (digital)	Altitude
				Decision Height
				Warning

DATA SOURCES AND ELEMENTS (TRW) (CONTINUED).

Source	Type	Data Rate	Recorder	Elements
VHF Nav	Analog/Discrete		8 mm (digital)	VOR/LOC Deviation
				Glideslope Deviation
				VOR/LOC Superflag
				Glideslope Superflag
				TO-FROM Flag
				GS/LOC Enable
				Marker Sensitivity
				Outer Marker Beacon
				Middle Marker Beacon
				Inner Marker Beacon
				Nav Ident
DME #1	Analog/Discrete		8 mm (digital)	Distance
				DME Valid
				DME Ident
Squat Switch	Discrete		8 mm (digital)	Weight On Wheels
Event Markers	Discrete		8 mm (digital)	Pilots
				Test Director #1
				Test Director #2
Weather	RS-232	1200 baud	8 mm (digital)	Weather Summary
Configuration File	electronic		8 mm (digital)	FPSVS Configuration
Experiment Notes	electronic		8 mm (digital)	Test Engineer Notes
MMW sensor	RS-170		Hi 8 mm VCR #1	video
FLIR sensor	RS-170		Hi 8 mm VCR #2	video
HUD Image	RS-170		Hi 8 mm VCR #3	video
Combiner Camera	RS-170		Hi 8 mm VCR #4	video
Intercom	Audio		Hi 8 mm VCRs	
IRIG-B	Audio	1 KHz	Hi 8 mm VCRs	Time
IRIG-B	Digital		8 mm (digital)	Time

DATA SOURCES AND ELEMENTS (HONEYWELL)

Source	Type	Data Rate	Recorder	Elements
Radar Receiver	10 bit digital	1 frame/4 s	SUN SPARC	Baseband Video
Radar Controller	8 bit digital	1 frame/4 s	SUN SPARC	Antenna Tilt
Inertial Navigation Sys	20 bits digital	1 frame/4 s	SUN SPARC	Position
Inertial Navigation Sys	15 bits digital	1 frame/4 s	SUN SPARC	Attitude
Inertial Navigation Sys	20 bits digital	1 frame/4 s	SUN SPARC	Inertial Altitude
Radar Altimeter	analog	1/frame/4 s	SUN SPARC	Altitude
IRIG-B	1 mS	1 frame/4 s	SUN SPARC	Time
Scan Converter	RS-170	30 frame/sec	S-VHS #1	Radar Image *
Intercom	audio	continuous	S-VHS #1	
IRIG-B	audio	continuous	S-VHS #1	Time
Combiner Camera	RS-170	30 frame/sec	S-VHS #2	
Intercom	audio	continuous	S-VHS #2	
IRIG-B	audio	continuous	S-VHS #2	Time

* includes IRIG-B, Baro Corrected Altitude, INS Position, Attitude on scan converter text.

Data Sources and Elements (Lear)

Source	Type	Data Rate	Recorder	Elements
Radar Receiver	12 bit digital	1 frame/10 s	PC- Hard Disk	Baseband Video
Radar Controller	8 bit digital	1 frame/10 s	PC- Hard Disk	AGC Step
Inertial Navigation Sys	20 bits digital	1 frame/10 s	PC- Hard Disk	Position
Inertial Navigation Sys	15 bits digital	1 frame/10 s	PC- Hard Disk	Attitude
Radar Altimeter	analog	1 frame/10 s	PC- Hard Disk	Altitude
IRIG-B	1 mS	1 frame/10 s	PC- Hard Disk	Time
Scan Converter	RS-170	30 frame/sec	S-VHS VCR #1	Radar Image*
IRIG-B	audio	continuous	S-VHS VCR #1	Time
Combiner Camera	RS-170	30 frame/sec	S-VHS VCR #2	
IRIG-B	audio	continuous	S-VHS VCR #2	Time

* includes IRIG-B, Baro Corrected Altitude, INS Position, Attitude on scan converted text.

Data Sources and Elements (JTD)

Source	Type	Integration Time	Recorder	Elements
FSSP Pod	digital	1 Sec	Digital Tape	Particle Size (fog)
OAP Pod	digital	1 Sec	Digital Tape	Particle Size (rain)
LWC Probe	digital	1 Sec	Digital Tape	liquid water content
ADC	analog	1 Sec	Digital Tape	TAT
Pitot/Static Transducers	analog	1 Sec	Digital Tape	Airspeed
Radar Altimeter	analog	1 Sec	Digital Tape	Altitude
Time (1 second res.)	digital		Digital Tape	Time

SYSTEM LEVEL PERFORMANCE ANALYSIS (TRW)

Analysis	Data Sources
Digital Analysis	
Plan view of trajectory	WOW, GPS, INS, VHF Nav
Crab angle vs. Range	WOW, GPS, INS
Standard deviation of centerline tracking error	WOW, GPS, INS
Profile view	WOW, GPS, INS
Projection of nominal glidepath on runway	WOW, GPS, VHF Nav
Std. Dev.of glideslope tracking error (ILS only)	WOW, GPS, VHF Nav
Plot of airspeed error vs. range to touchdown	WOW, GPS, ADC
Pilot commentary noting identified obstacles	Time, Intercom, Video
Touchdown sink-rate discrete	WOW, GPS, INS, RA
Hodograph of sink-rate vs. altitude	WOW, GPS, INS, RA
Longitudinal touchdown position X_{TD} discrete	WOW, GPS, INS
Lateral touchdown position (Y_{TD})	WOW, GPS, INS
Touchdown heading discrete	WOW, GPS, INS
Touchdown bank angle discrete	WOW, GPS, INS
Touchdown lateral acceleration discrete	WOW, GPS, INS
Safety Pilot comments	Time, Intercom
Image Quality	
Contrast	Time, MMW & FLIR Video, Evnt Marker
Sharpness	Time, MMW & FLIR Video, Evnt Marker
Variability	Time, MMW & FLIR Video, Evnt Marker
Image Quality	Time, MMW & FLIR Video, Evnt Marker

MMW Sensor Performance Analysis (GTRI)

Analysis	Data Sources
Br (Power Received from Runway)	Raw MMW Data, INS, Weather, Gnd Truth
Bt (Power Received from Terrain)	Raw MMW Data, INS, Weather, Gnd Truth
Contrast	Raw MMW Data, INS, Weather
Sharpness	Raw MMW Data, INS, Weather
Variability	Raw MMW Data, INS, Weather
Attenuation	Raw MMW Data, INS, RA, Weather, Gnd Truth
Volumetric Backscatter	Raw MMW Data, INS, RA, Weather, Gnd Truth
Reflectivity (σ°) (Runway and Terrain)	Raw MMW Data, INS, RA, Weather, Gnd Truth

Meteorological Analysis (JTD)

Analysis	Data Sources
Dropsize Distribution (1 Hz)	Time, RA, Pitot/Static Transducers, ADC (TAT), FSSP, OAP
Average Distribution (30 ft)	Time, RA, Pitot/Static Transducers, ADC (TAT), FSSP, OAP
Air Temperature Profile	Time, RA, ADC (TAT)
Rainfall Profile	Time, RA, Pitot/Static Transducers, ADC (TAT), FSSP, OAP
Humidity	Weather Report at Runway

APPENDIX E-DESCRIPTION OF FLIGHT TEST SYSTEM

A. Nose Area Modifications

B. Weather Sensors

C. Navigation Sensors

D. Video data sensors and recording

H. Head Down Display

F. Racks

G. Structural Modifications

H. Electrical

AIRCRAFT SENSOR CONFIGURATION

Supplier	Description	CONFIGURATION Ka-Band (Primary)	CONFIGURATION W-Band (Backup)
Honeywell	MMW sensor (35 GHz)	√	
Honeywell	data collection rack	√	
Norton	Radome (35 GHz)	√	
Lear	MMW sensor (94 GHz)		√
Lear	data collection racks		√
Norton	Radome (94 GHz)		√
Kodak	FLIR (3-5μm)	√	√
TRW	Data Acquisition System	√	√
JTD	liquid water content probe	√	√
JTD	particle size #1 pod	√	√
JTD	particle size #2 pod	√	√
GEC	HUD	√	√
TRW	Combiner Camera	√	√
TRW	Equipment Rack	√	√
TRW	Test Director Station	√	√
TRW	Test Engineer Station	√	√
TRW	MMW Engineer Station	√	√
TRW	Observers Station	√	√

FPSVS SPECIAL EQUIPMENT SUMMARY

Description	Location	Comments
Honeywell Antenna	nose bulkhead	waveguide interface with R/T unit
Honeywell R/T unit	nose shelf	18 " max cable length from antenna
Lear Antenna	nose bulkhead	waveguide interface with Tx/Rx unit
Lear Tx/Rx	nose shelf	
Lear RIU	nose shelf	
Lear Power Supply #1	nose shelf	
Kodak FLIR camera	nose bulkhead	
Kodak FLIR cooling pump	nose bulkhead	
Kodak FLIR power supply	nose bulkhead	
Kodak FLIR electronics	nose bulkhead	
Combiner Camera	Glareshield	
Equipment Racks	Cabin	
Test Director (TD1)		
Test Engineer(EN1)		
MMW Equipment (EQ1)		
Observer (OB1)		
DAS (DA1)		
DAS (DA2)		
Sensor Data (SD2)		primary configuration
Sensor Data (SD3)		primary configuration
Head Up Display	Right Overhead	tray and cables for both seats
Head Down Display	5 tube EFIS	right ADI and center tube replaced
Weather sensors		
particle size #1	wing	pylon developed by subcontractor
particle size #2	wing	pylon developed by subcontractor
total water content	cheek panel	
transformer		
pitot/static transducer		

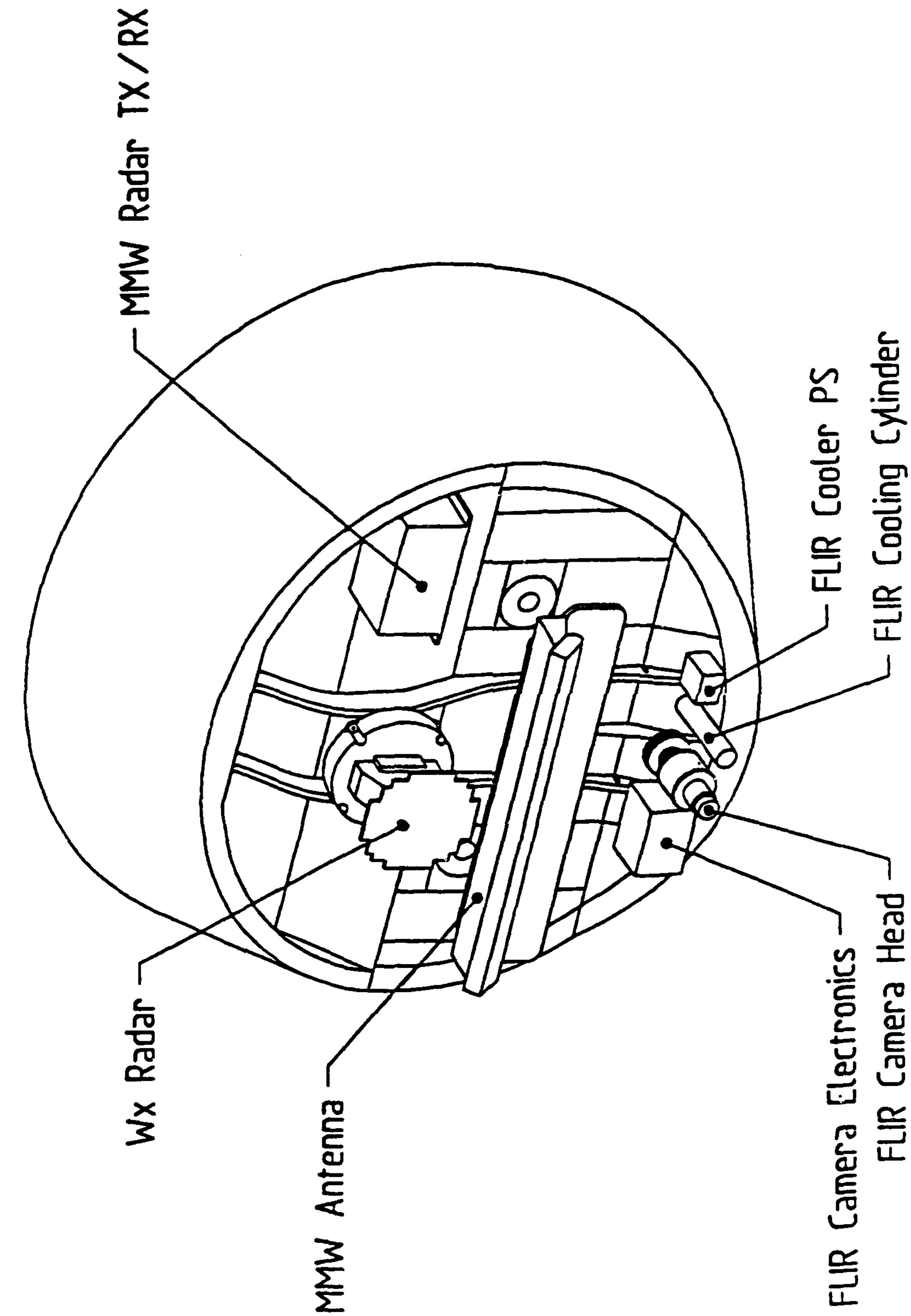
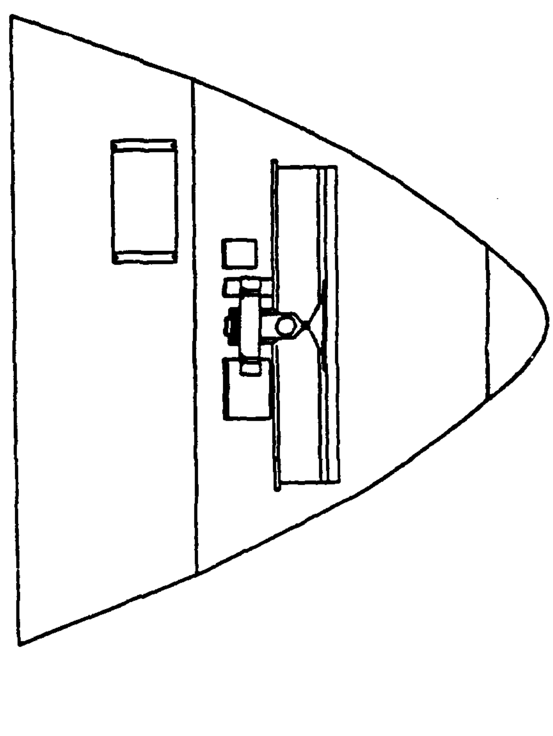


Figure E-1. Honeywell MMW Installation Arrangement

Component Mounting Definition
(Geometric Center of Mounting Pattern Plane)

Component	FS	WL	BL	Pitch
Wx Radar	39.79	92.36	0.00	0
MMW Antenna	36.62	80.24	0.00	0
MMW Radar Tx / Rx	49.56	87.00	13.00	0
FLIR Camera Head	32.02	66.86	0.00	-5
FLIR Cooling Cylinder	33.42	65.76	4.00	-5
FLIR Cooler PS	39.88	65.44	7.50	-5
FLIR Camera Electronics	39.33	65.39	6.50	-5



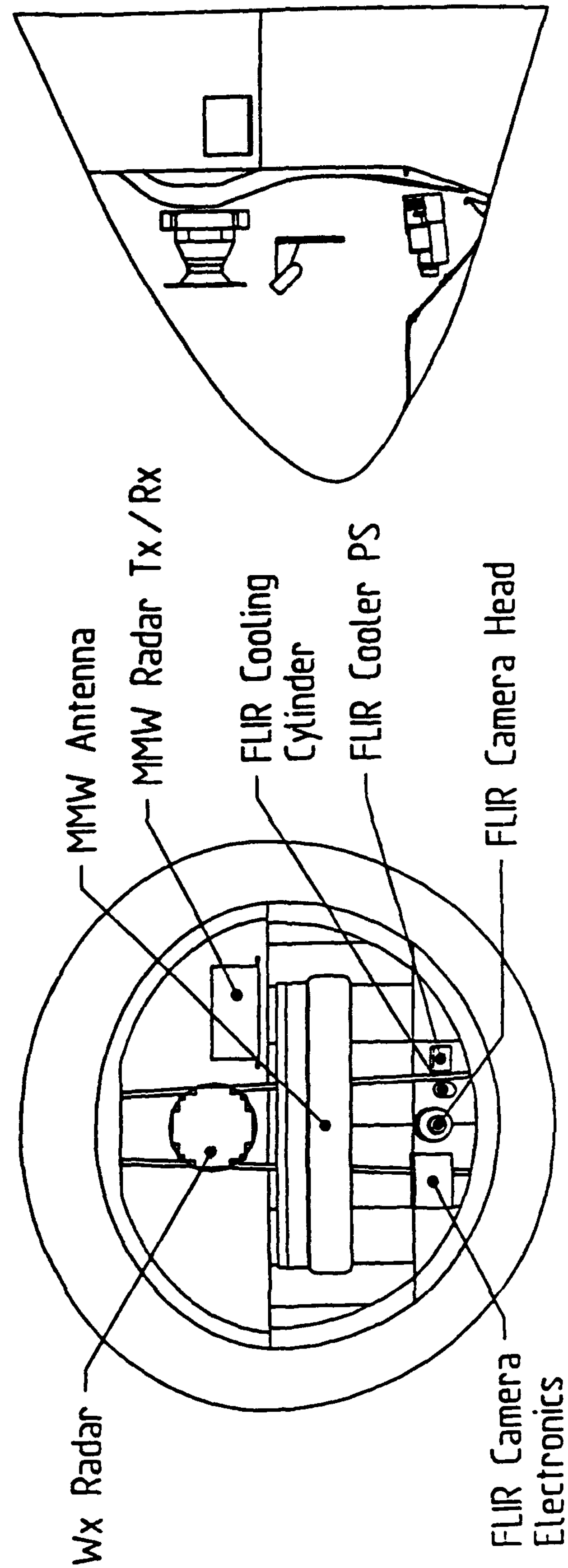


Figure E-2. Honeywell MMW Installation Definition

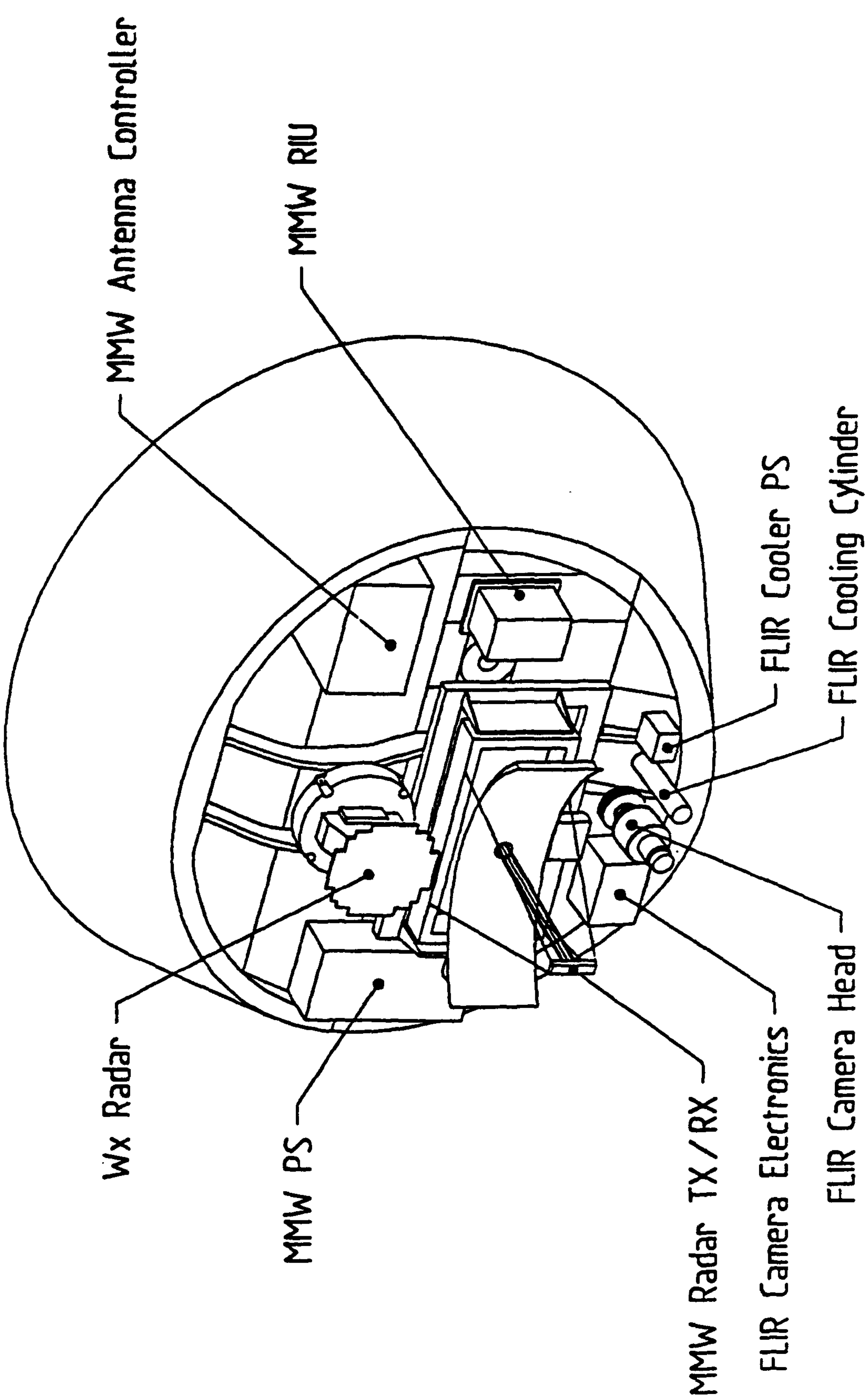
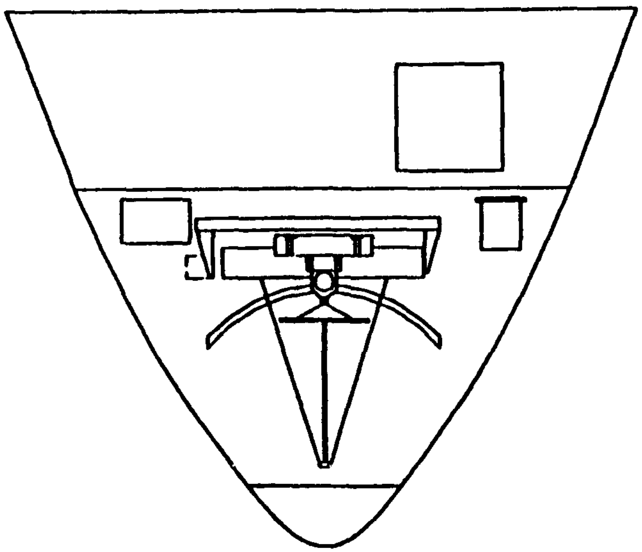
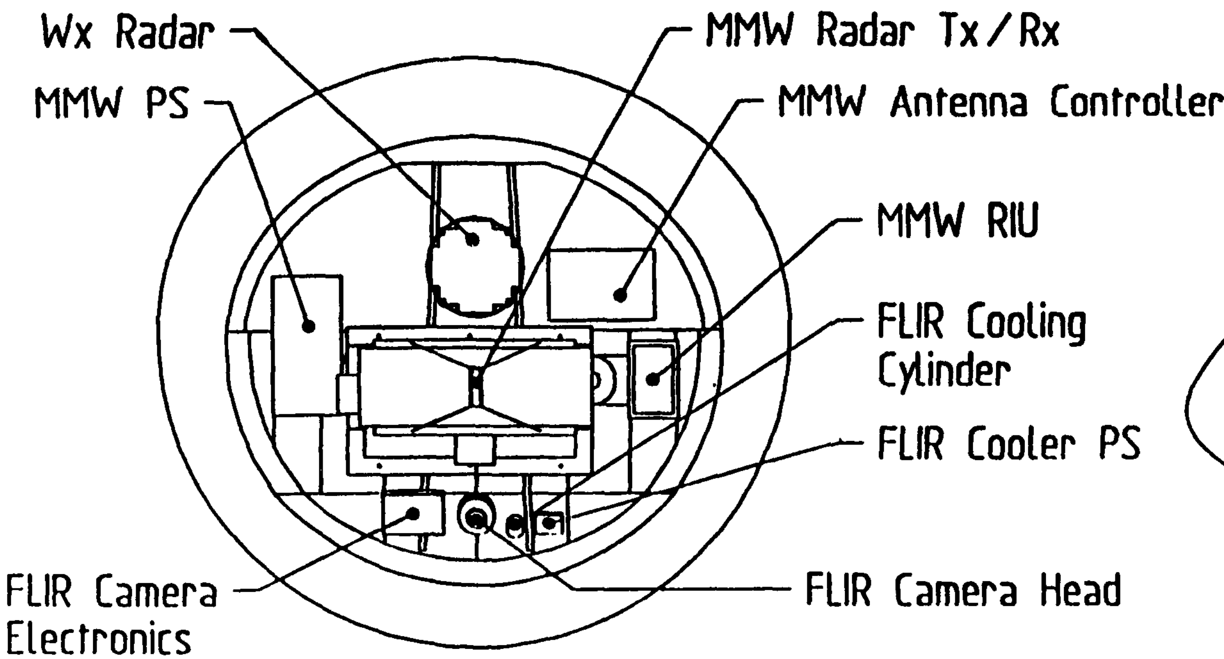


Figure E-3. Lear MMW Installation Arrangement

Component Mounting Definition (Geometric Center of Mounting Pattern Plane)				
Component	FS	WL	BL	Pitch
Wx Radar	39.79	92.36	0.00	0
MMW Antenna	41.50	78.86	0.60	0
MMW Antenna Controller	51.75	87.00	13.00	0
MMW RIU	43.50	81.00	18.35	0
MMW PS	43.50	84.50	17.20	0
FLIR Camera Head	32.02	66.86	0.00	-5
FLIR Cooling Cylinder	33.42	65.76	4.00	-5
FLIR Cooler PS	39.88	65.44	7.50	-5
FLIR Camera Electronics	39.33	65.39	6.50	-5





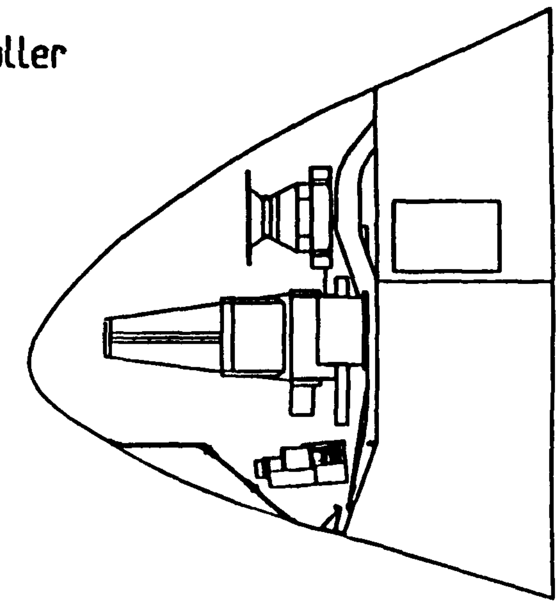


Figure E-4. Lear MMW Installation Definition

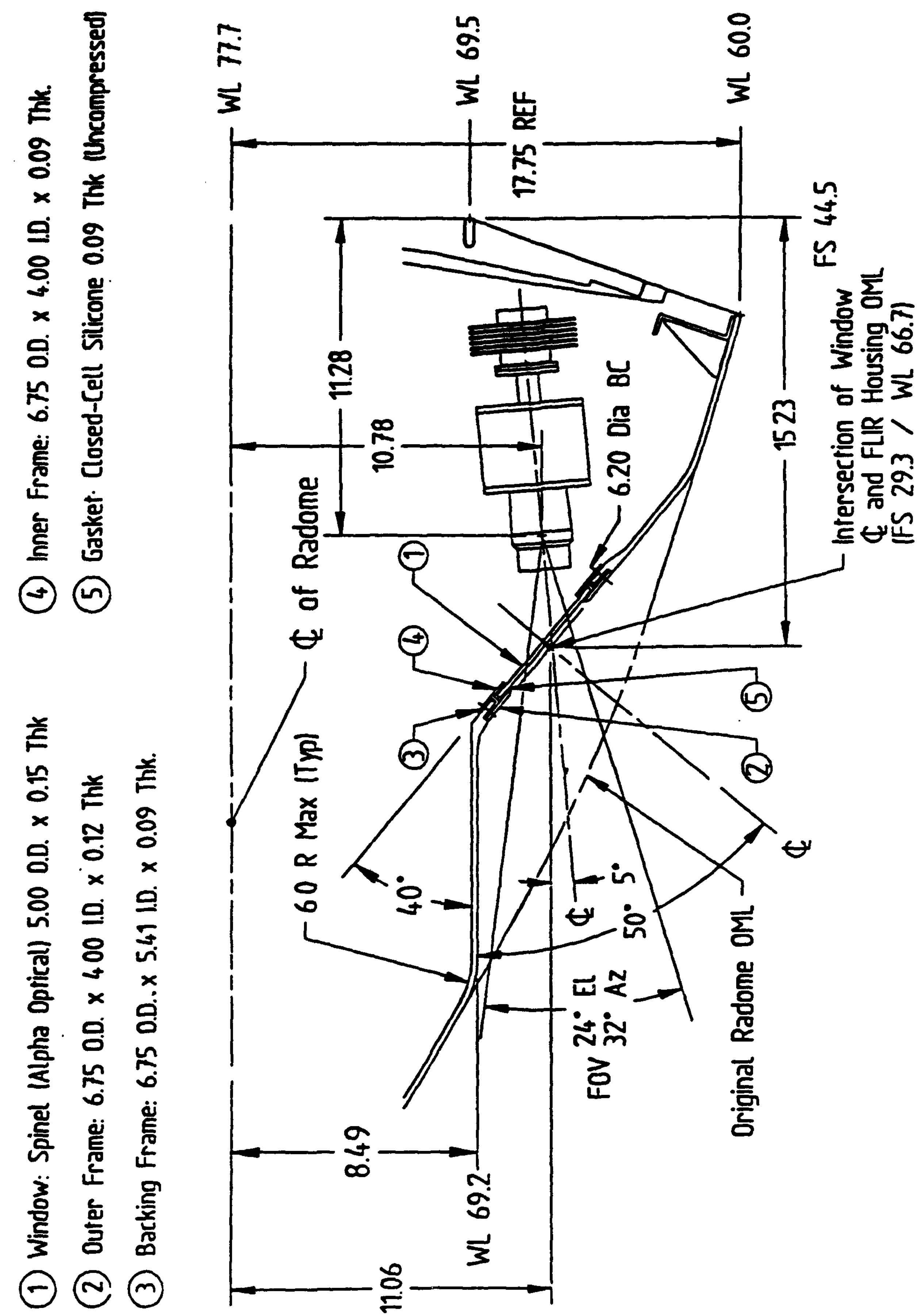


Figure E-5. FLIR Radome Modification

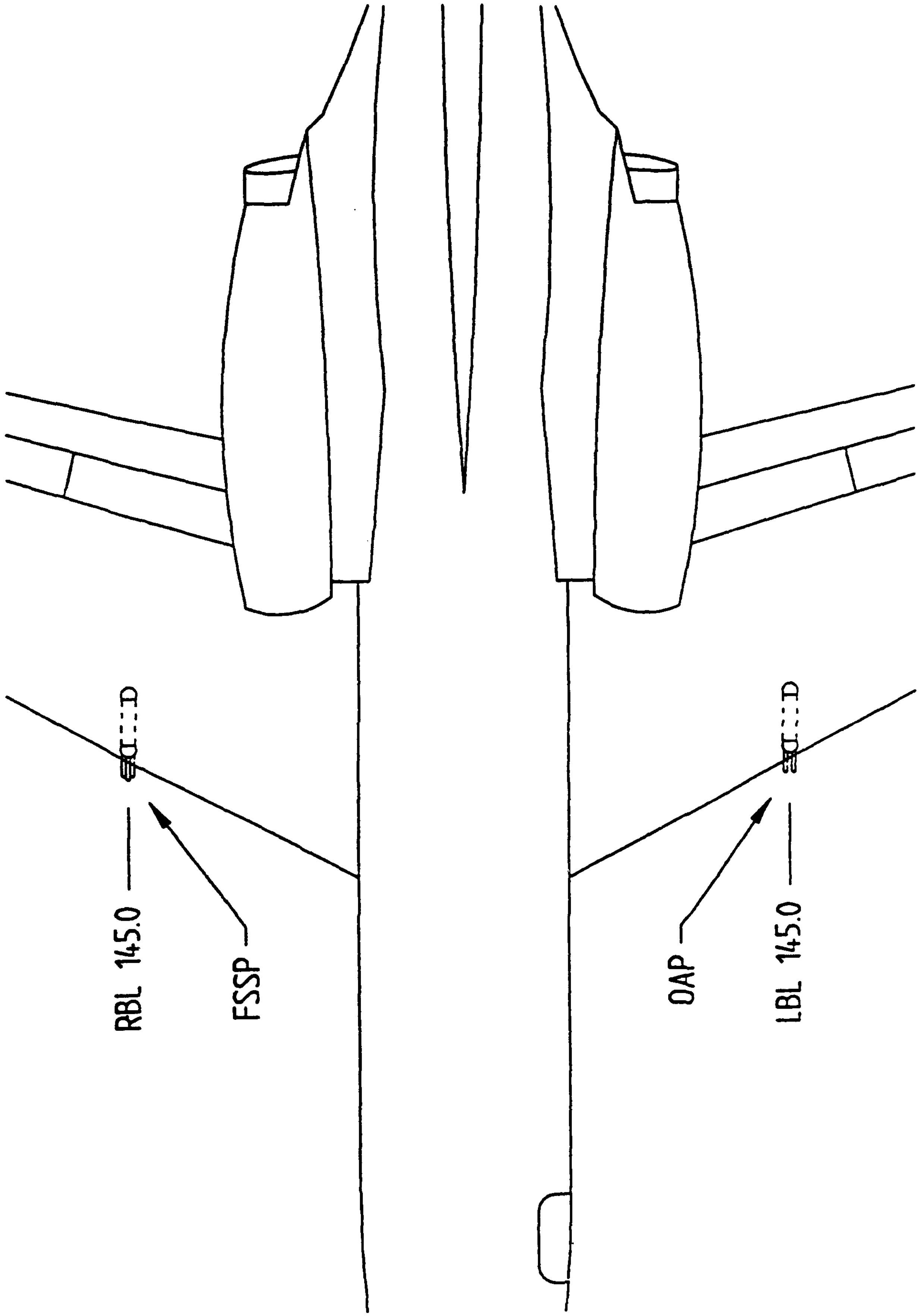


Figure E-6. JTD FSSP/OAP Weather Sensor

DROPLET SIZE PROBES (INTERCHANGEABLE)

Model	Weather	Channels	Resolution (microns)	Range (microns)	Physical
FSSP-100	Fog	15	0.5	0.5 to 8.0	Narrow Arm
			1.0	1.0 to 16.0	
			2.0	2.0 to 32.0	
			3.0	2.0 to 47.0	
OAP-200X	Cloud	15	10 (min)	10 - 150	Narrow Arm
			200 (max)	200 - 3,000	
OAP-	Cloud			- 1,500	Narrow Arm
OAP-200Y	Precipatation	15	300	300 - 4,500	Wide Arm (23 cm)

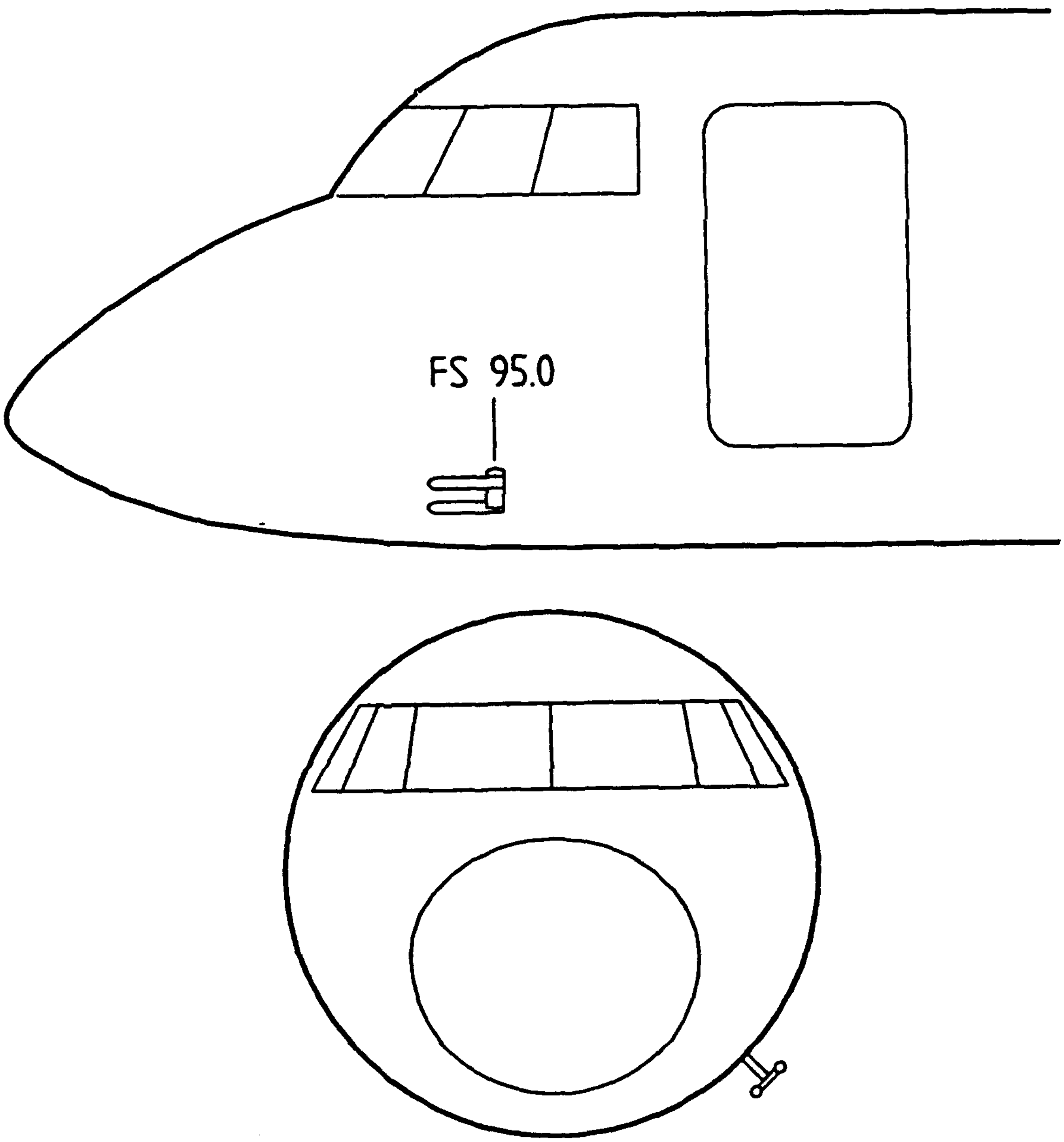


Figure E-7. JTD JW Weather Sensor Installation

AIRCRAFT AVIONICS

1 Weather Radar System; one Honeywell WC-650 (15" antenna)

2 Electronic Flight Instrument System; one Honeywell 5 tube EFIS

3 Air Data Computer System; one Honeywell AZ-800

4 Altimeter Indicators

5 Vertical Speed Indicators

6 VHF Communications System; triple Collins VHF-20

7 HF Radio; two King KHF-950 w/ Motorola NA-135 SELCAL

8 VHF Navigation System, two Collins VIR-30

9 Avionic Power Switching

10 Inertial Navigation System; two Litton LTN-92

11 VLF/Omega; one Universal UNS-1Jr

12 Distance Measurement Equipment System; one Collins DME-42 and one DME-40

13 Automatic Direction Finder System; two Collins ADF-60A

14 Flight Director System; two Honeywell FZ-500

15 Transponders; two Collins TDR-90

16 Radio Altimeter System, one Collins ALT-55B

17 Cockpit Voice Recorder; Fairchild A-100

18 Flight Phone; Wolfsberg Flitefone VI

19 Angle of Attack; Teledyne AOA

20 GPS; Marconi

VIDEO RECORDERS

VCR	Horizontal Resolution	Audio Recording	Media Size (inches)	Media Size Length	Users
Hi 8	400 lines	Stereo PCM	0.3 x 3.4 x 2.5	2 hours	TRW
S-VHS	400 lines	Stereo Analog	1.0 x 7.4 x 4.0	2 hours	Honeywell, Lear
VHS	300 lines	Stereo Analog	1.0 x 7.4 x 4.0	3 hours	Honeywell

MAJOR CHARACTERISTICS OF THE HDD DISPLAY

Maximum Dimensions	5.000" (h) x 6.000" (w) x 16" (d)
Signal Standard	EIA RS-170 (black and white), 525 lines/60 fields, 2:1 interlace
Horizontal Resolution	600 TV lines minimum (Active Area)
Video Input	1 volt p-p composite, negative sync, 75 Ω (switchable to Hi Z)
Video Bandwidth	10 MHz
Raster Size	6" diag desired (4:3 aspect ratio), 4" diag minimum
Power	28 VDC
Brightness	200 ft Lambert (sunlight viewable desired)
Contrast Ratio	7:1 at 10,000 ft candles
Altitude	30,000 Ft.
Temperature	0 to 50° C
Humidity	100%
Vibration	
Shock	
EMI Shielding	As necessary
Minimum User Controls	Brightness and Contrast

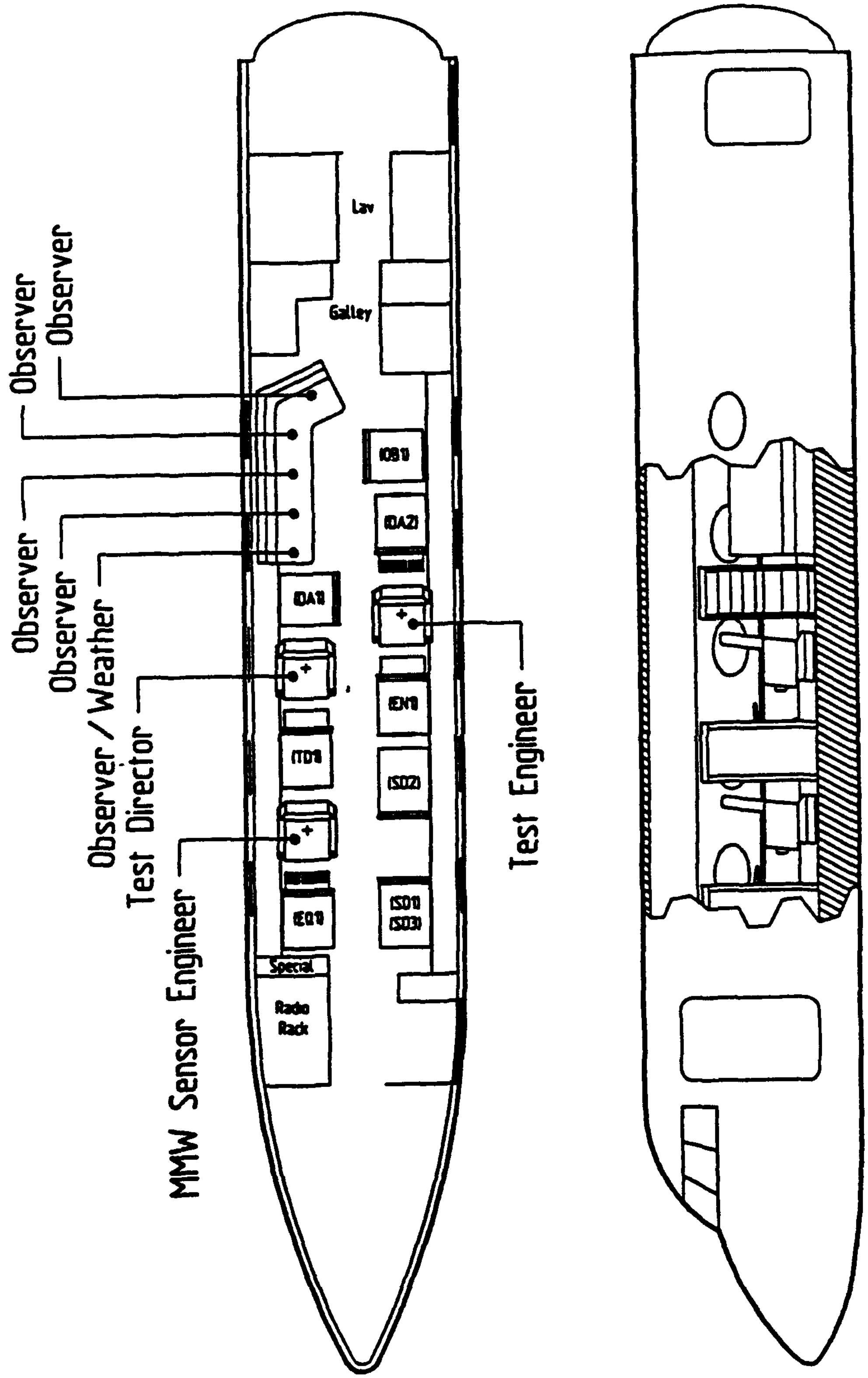


Figure E-8. Cabin Equipment Arrangement

WORK STATION RESOURCES

Resources	Engineering	Director	MMW	Observers
Video Monitors	2	1	1	1
Video Selector	X	X	X	X
Status Indicators	X			
Recording Control	System		MMW	Wx
Intercom	X	X	X	X
Interface Unit	X			
Work Surface	X	X		

WORKSTATIONS

Crew	Description (Orientation)
MMW Sensor Engineer	90° swivel (front to left)
Test Engineer	180° swivel (front to right to back)
Flight Director	no swivel (facing front)
Wx/Host/Observer	5 passenger couch (facing left)
	jump seat (front forward)

VHF COMMUNICATIONS ANTENNA

Parameter	Requirement
Mounting Location	underside of the aircraft
Frequency Range	118 MHz through 136 MHz
Antenna Pattern	omni-direction
Antenna Gain	no gain
VSWR	< 2:1
Cable	TBD
Radio Connector	BNC

INTERCOM CONFIGURATION

	Cockpit	Cabin	VHF Radio
Pilot	Talk/Listen	Listen	Talk/Listen
Co-Pilot	Talk/Listen	Listen	Talk/Listen
Test Director	Talk/Listen	Talk/Listen	Talk/Listen
Test Engineer	Listen	Talk/Listen	
Sensor Engineer	Listen	Talk/Listen	
Host/Wx Sensor	Talk/Listen	Talk/Listen	Listen
Observers (Qty 4)	Listen	Talk/Listen	Listen

OUTPUTS

A ICS Cabin Loop

B Pilot (Mic, Headset, and Speaker)

C Co-Pilot (Mic, Headset, and Speaker)

FPSVS POWER REQUIREMENTS

Power Type	Regulation	Phases	Frequency	Continuous Power
+28 VDC	+/- 3 VDC			3000 Watts
115 VAC (Wild AC)	+/- 10 VAC	3 Phase	400 +/- 50 Hz	750 VA
115 VAC	+/- 10 VAC	1 Phase	400 +/- 4 Hz	1500 VA
115 VAC	+/- 10 VAC	1 Phase	60 +/- 1.0 Hz	2500 VA

AIRCRAFT ELECTRICAL INTERFACES

H/W	Model #	Signal	Scale
INS #1	LTN-92	Data Bus	ARINC 429, 100 Kbps
INS #2	LTN-92	Data Bus	ARINC 429, 100 Kbps
GPS		Data Bus	ARINC 429, 13.9 Kbps
HUD		Control Bus	ARINC 429, 100 Kbps
		Test Bus	ARINC 429, 100 Kbps
		Reprogrammer (IN)	ARINC 429, 100 Kbps
		Reprogrammer (OUT)	ARINC 429, 100 Kbps
ADC	AZ-800	Data Bus	ARINC 429, 13.9 Kbps
		Corrected Baro (Coarse)	Alt = $((V_o / V_{ref}) \times 75{,}000) - 12{,}500$ feet
		True Air Speed (TAS)	TAS = $(V_o / V_{ref}) / 0.000310186$ knots
		True Air Temp (TAT)	TAT = $((V_o / V_{ref}) / 0.012087)^2 - 273273$ °C
DME #1	DME-40	Distance	Distance = $V_o \times 25$ nmi
		DME Valid	28 VDC= VALID
		DME IDENT (morse code)	Audio (1367 Hz)
DME #2	DME-42	Distance	Distance = $V_o \times 25$ nmi
		DME Valid	28 VDC= VALID
		DME IDENT (morse code)	Audio (1367 Hz)
VHF Nav. #1	VIR-30	VOR/LOC Deviation	VOR Scale: 150 mV for 10° off course LOC Scale: 90 mV for 0.093 DDM (4 dB)
		Glideslope Deviation	Scale: 78 mV for 0.091 DDM (2 dB)
		VOR/LOC Superflag	28 VDC= VALID
		Glideslope Superflag	28 VDC= VALID
		TO/FROM Flag	positive = TO, negative = FROM
		GS/LOC Enable (Delayed)	28 VDC= RCVNG VOR
		Marker Beacon Sensitivity	open = LOW SENS, gnd = *HIGH SENS*
		Outer Beacon	Audio (400 Hz)
		Middle Beacon	Audio (1300 Hz)
		Inner Beacon	Audio (3000 Hz)
		NAV IDENT (morse code)	
		NAV Bearing	3-wire Synchro, 16.2 VAC

AIRCRAFT ELECTRICAL INTERFACES CONTINUED.

H/W	Model #	Signal	Scale
VHF Nav. #2	VIR-30	VOR/LOC Deviation	VOR Scale: 150 mV for 10° off course LOC Scale: 90 mV for 0.093 DDM (4 dB)
		Glideslope Deviation	Scale: 78 mV for 0.091 DDM (2 dB)
		VOR/LOC Superflag	28 VDC= VALID
		Glideslope Superflag	28 VDC = VALID
		TO/FROM Flag	positive = TO, negative = FROM
		GS/LOC Enable (Delayed)	28 VDC = RCVNG VOR
		Marker Beacon Sensitivity	open = LOW SENS, gnd = HIGH SENS
		Outer Beacon	Audio (400 Hz)
		Middle Beacon	Audio (1300 Hz)
		Inner Beacon	Audio (3000 Hz)
		NAV IDENT (morse code)	
		NAV Bearing	3-wire Synchro, 16.2 VAC
ADF #1	ADF-60A	ADF Bearing	3-wire Synchro, 16.2 VAC
ADF #2	ADF-60A	ADF Bearing	3-wire Synchro, 16.2 VAC
Radar Alt	ALT-55B	Altitude	Gradient: 20 mV/ft between -20 to 500 ft Gradient: 10.4 V + 3 mV/ft Alt > 500 ft.
		Decision Height	20 uA (<30 VDC) = ABOVE, GND = BELOW
		Warning	28 VDC = VALID, < 20 uA = NOT VALID
Squat Switch	Weight On Wheels (WOW)	open = AIR, GND = GROUND	
Yoke		Yoke Pitch	Potentiometer, 500Ω
		Yoke Roll	Potentiometer, 500Ω
		Video Select	Toggle Switch
		Event Marker	Toggle Switch

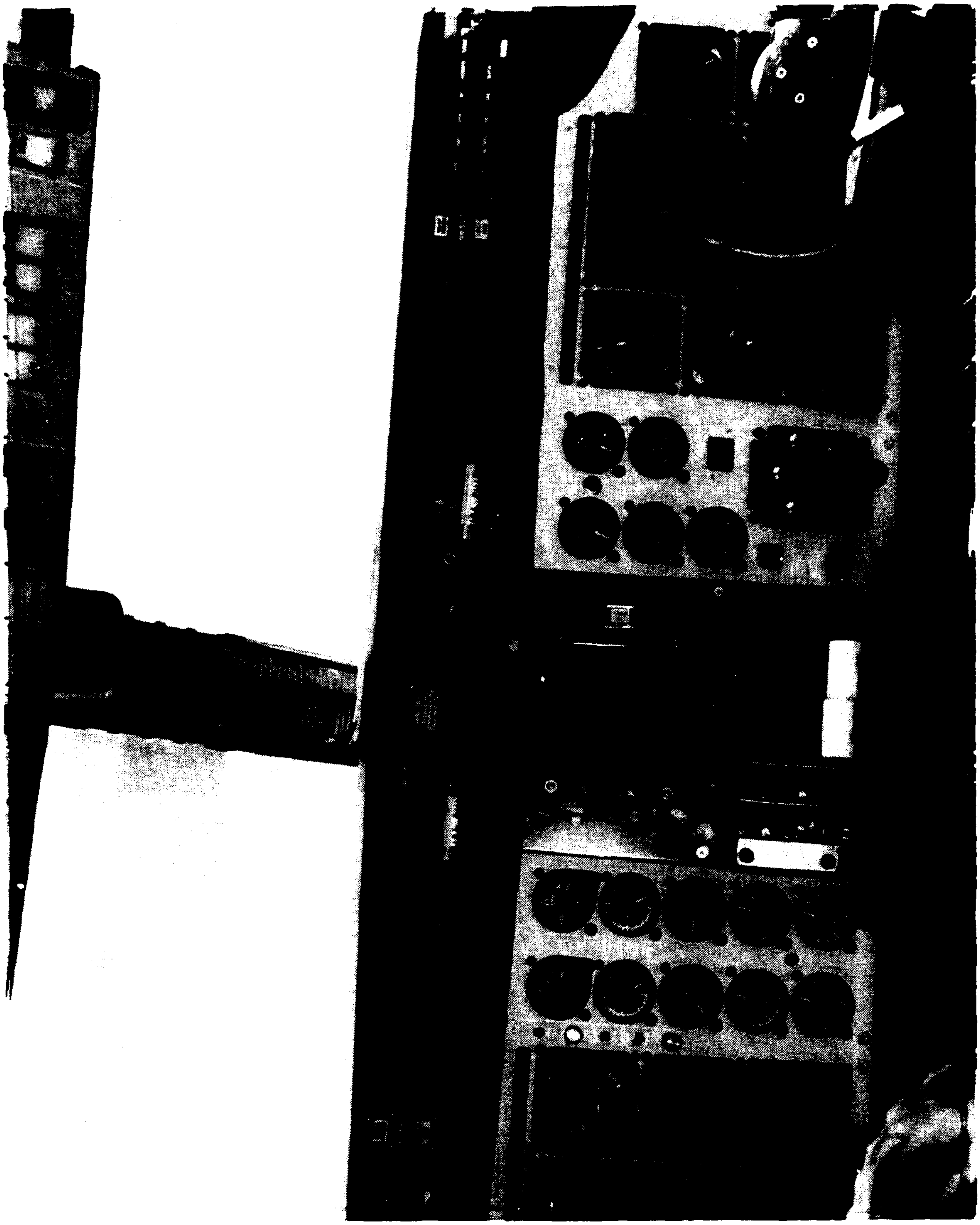


Figure E-9. Cockpit Instrumentation

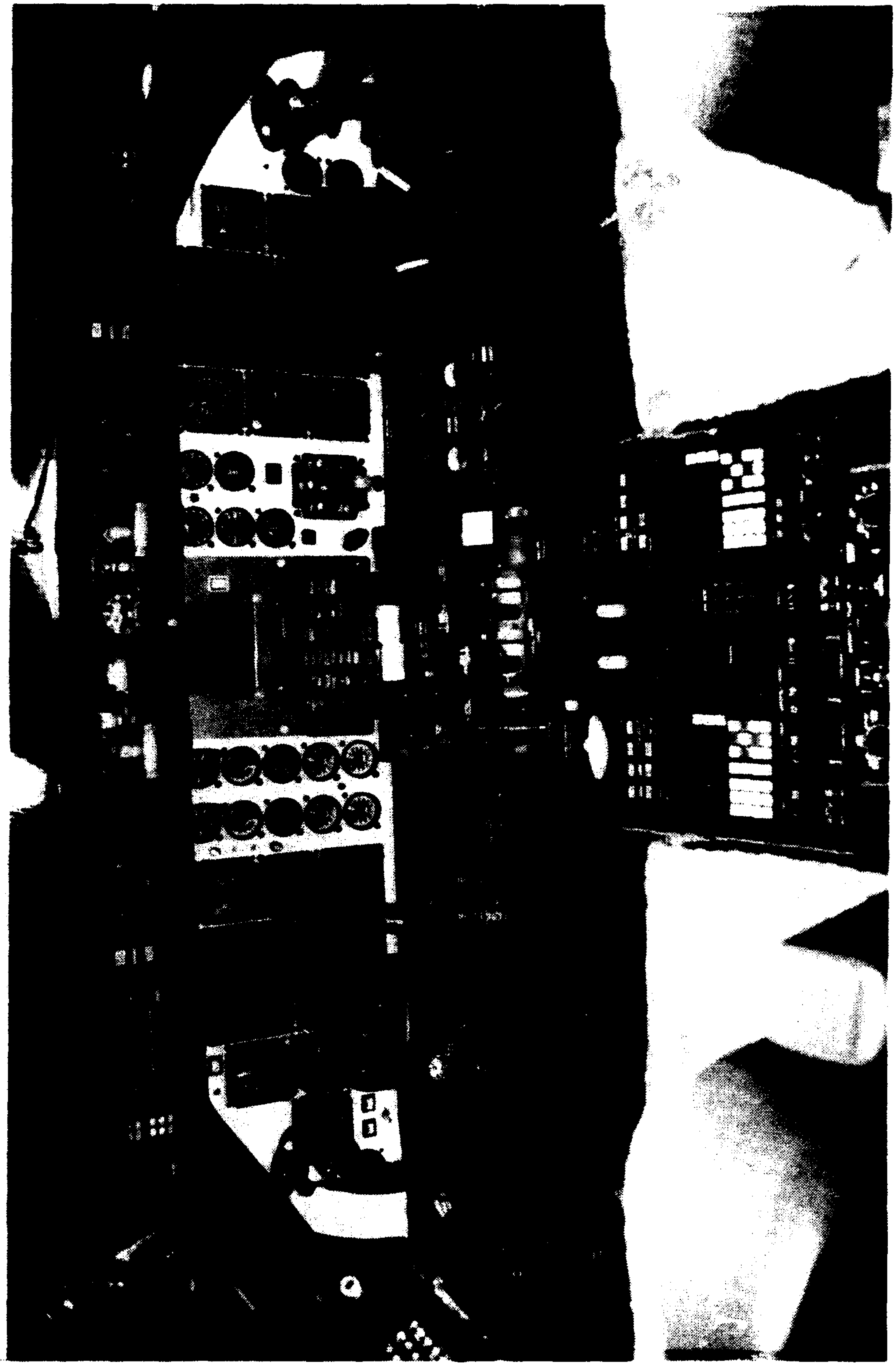


Figure E-10. Cockpit Instrumentation

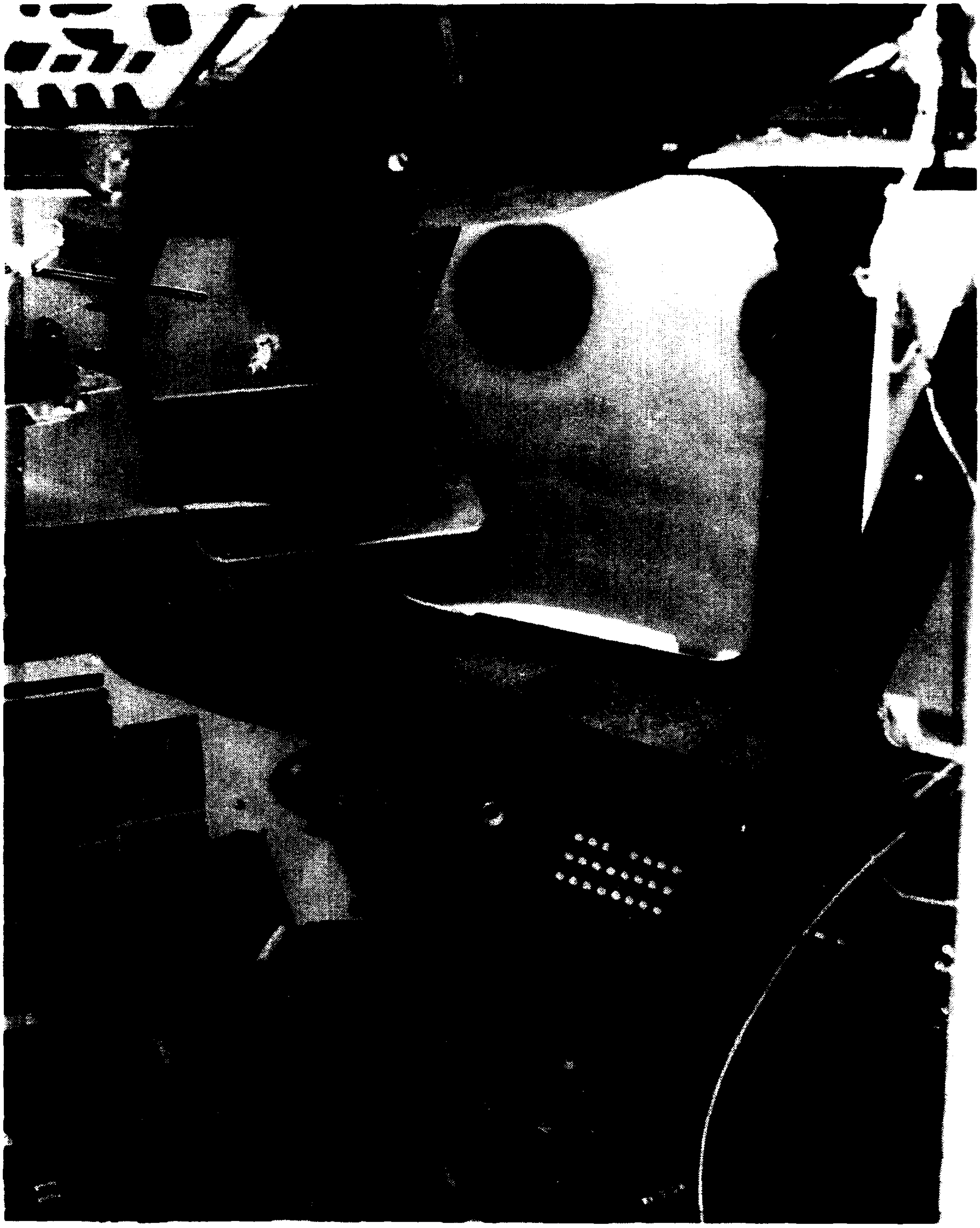


Figure E-11. Head-Up Display

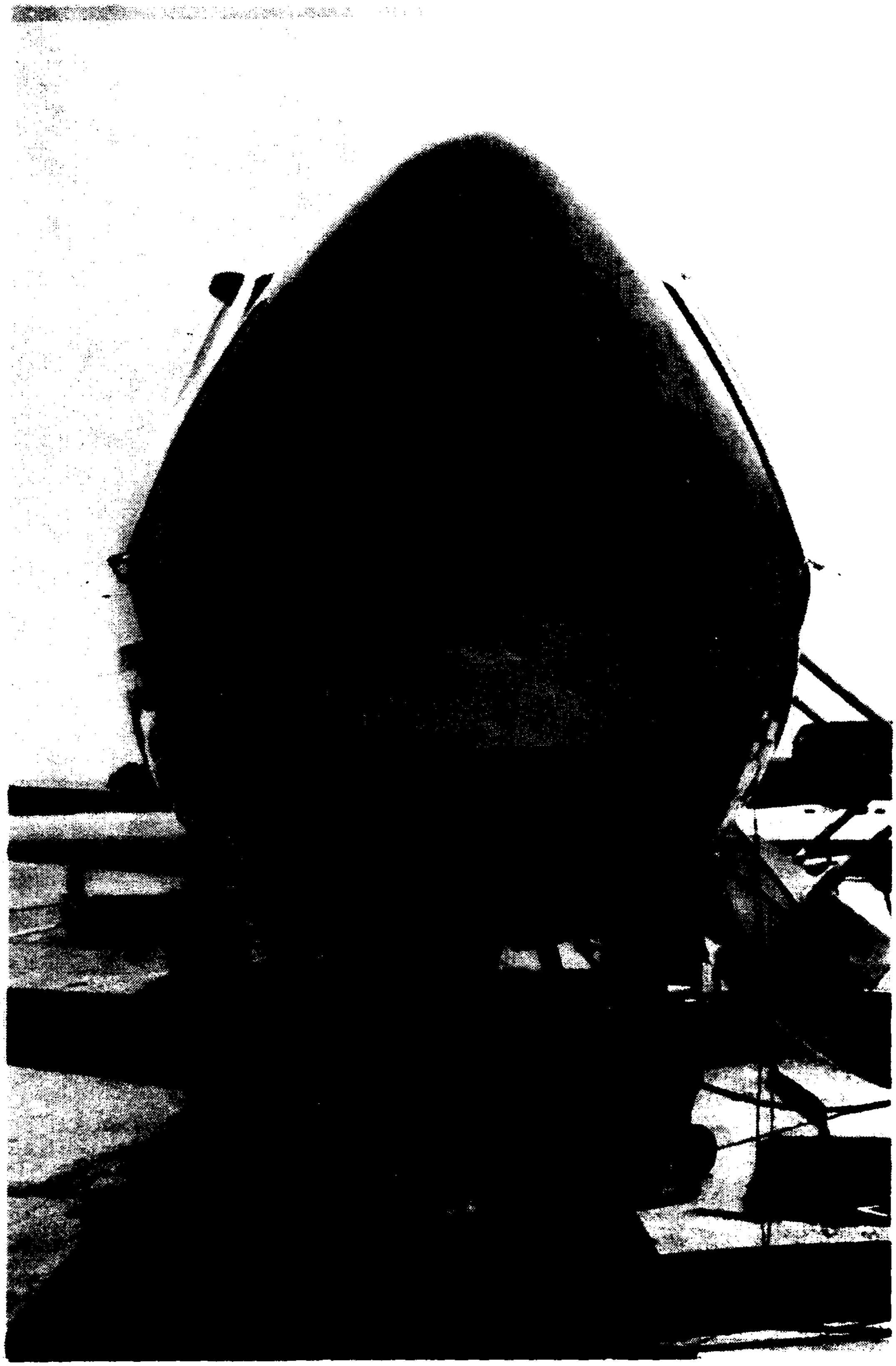


Figure E-12. FLIR Window on the Radome

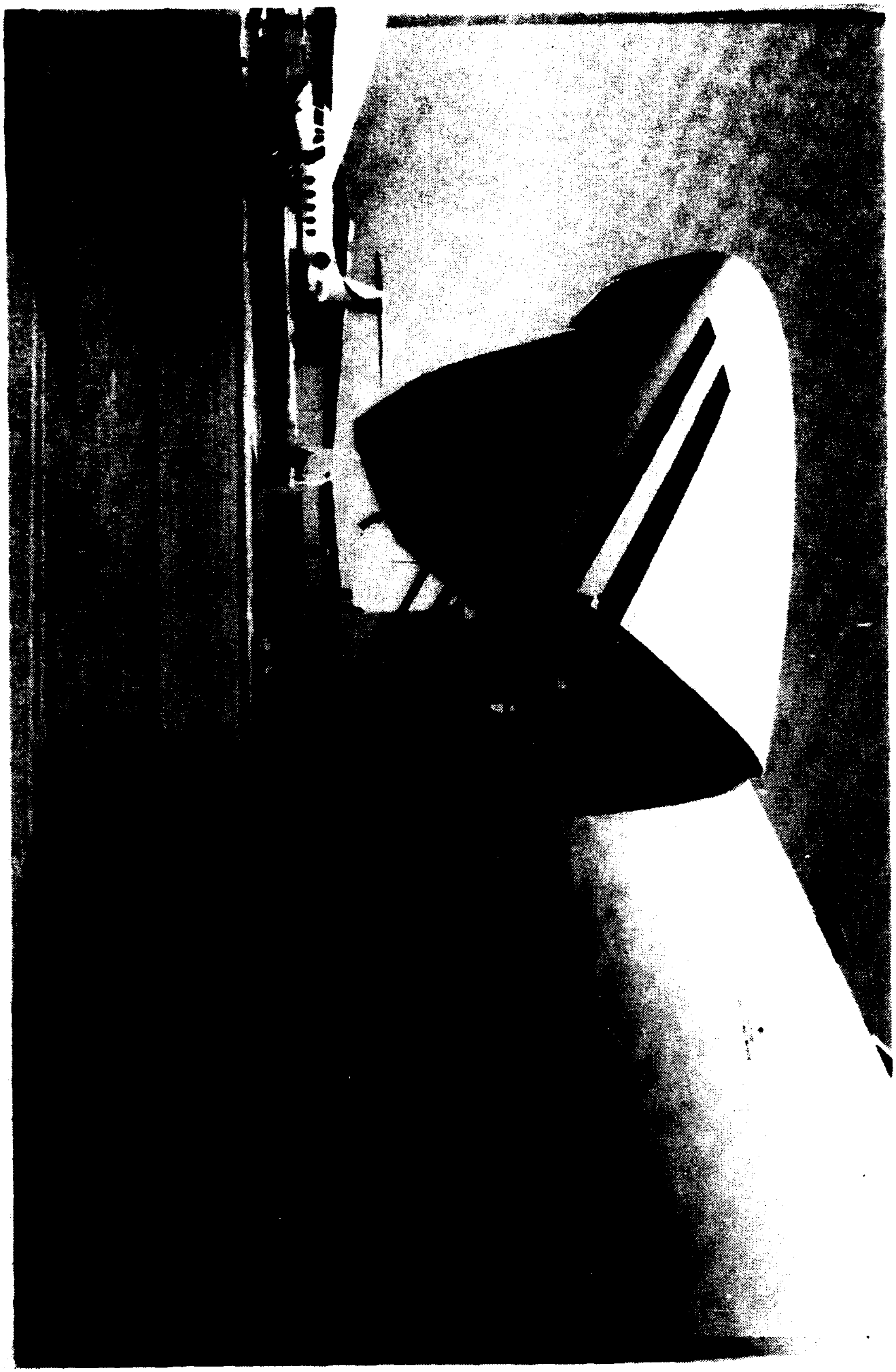


Figure E-13. Radome Area Modifications

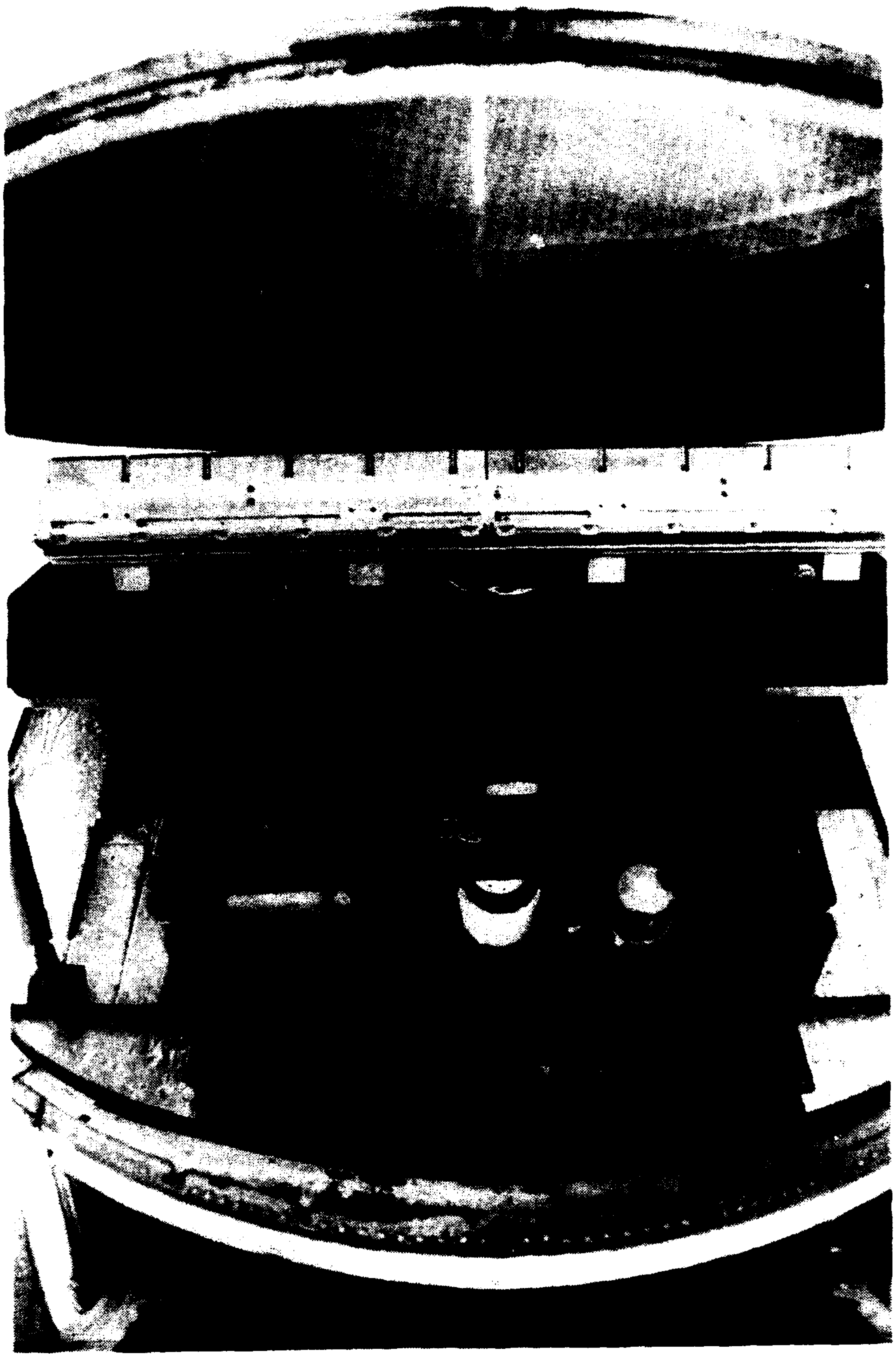


Figure E-14. MMW Antenna and FLIR Camera Located in Nose

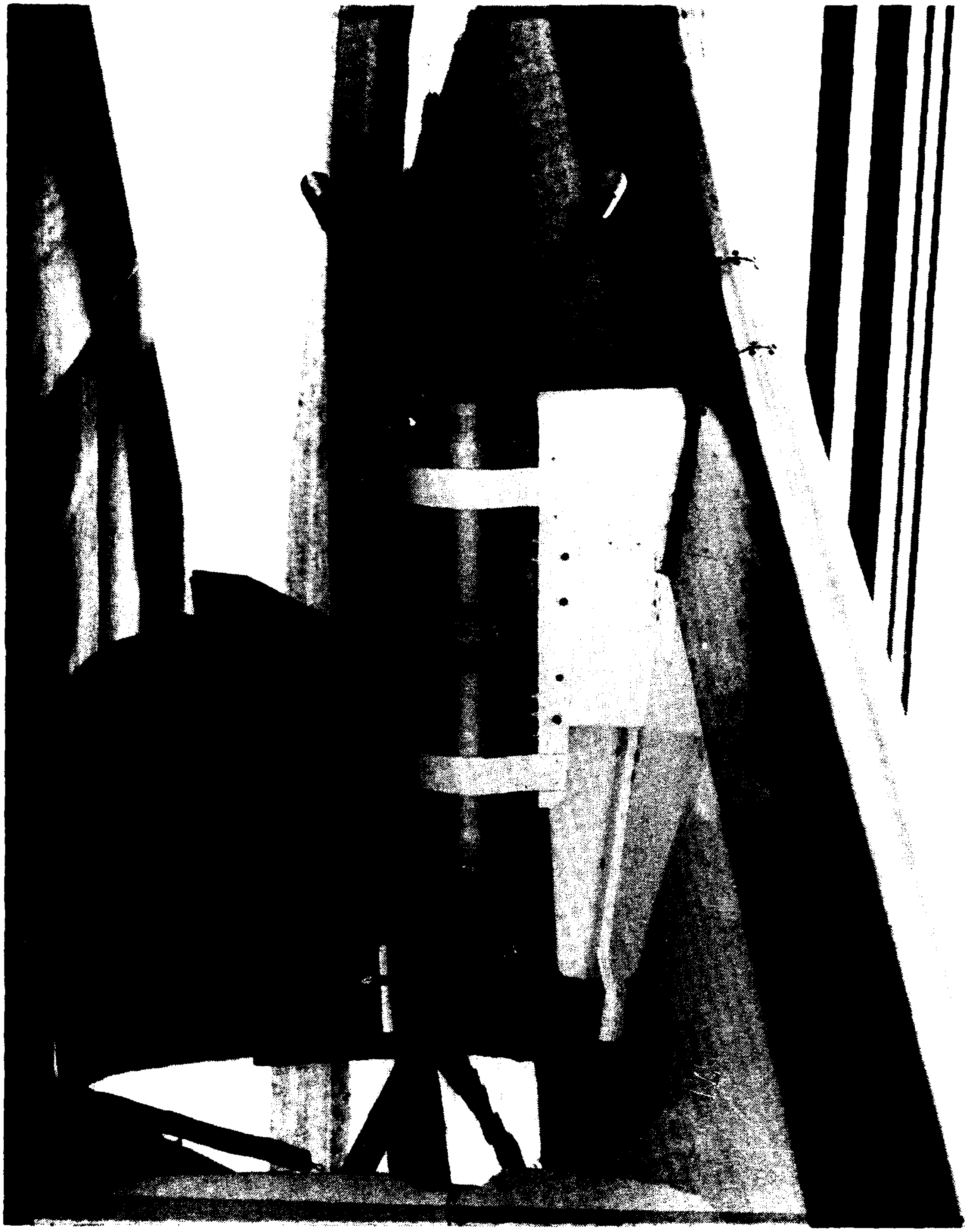


Figure E-15. Wide-Arm Precipitation Probe

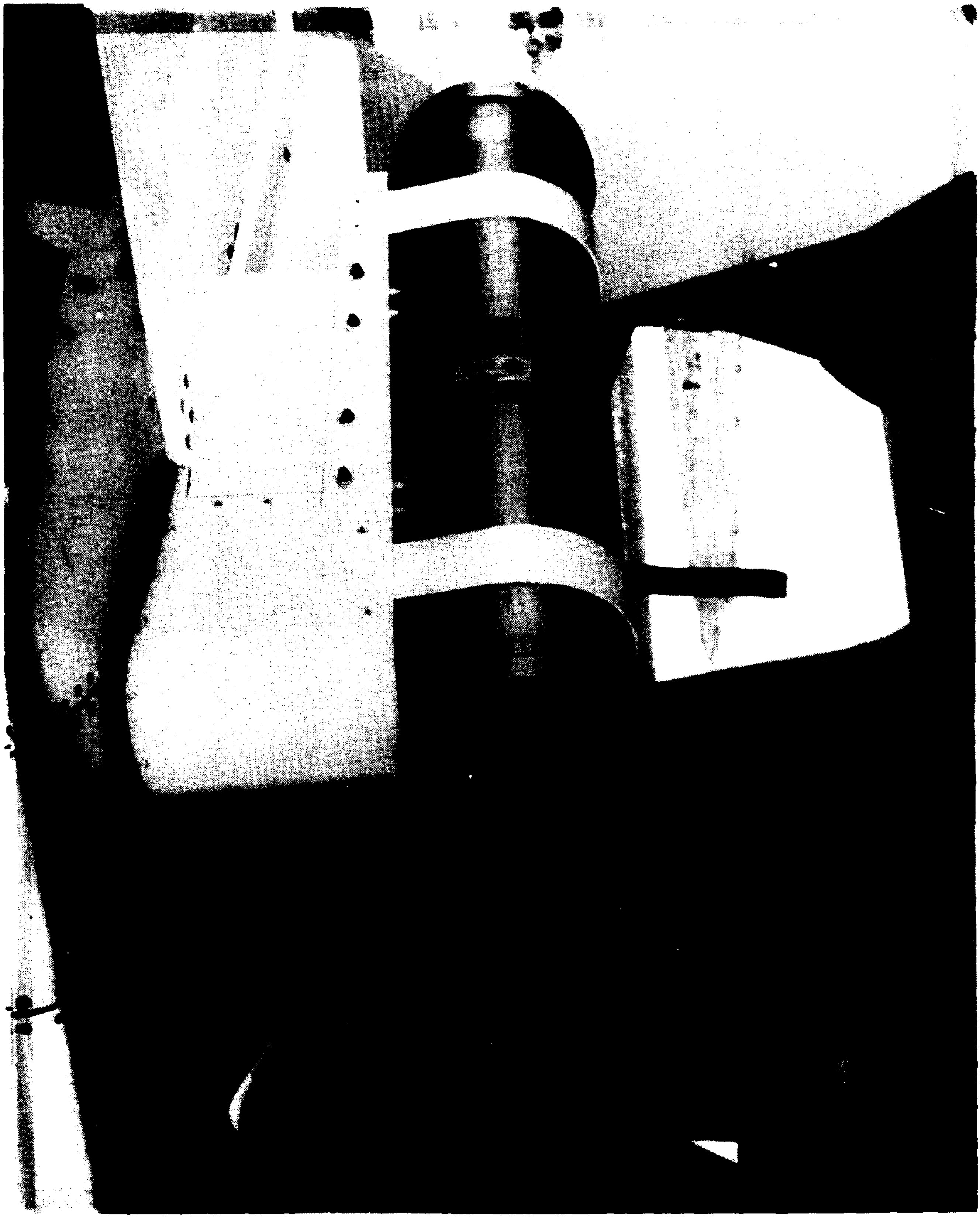


Figure E-16. Wide-Arm Precipitation Probe

Figure E-17. Video Recorder Rack

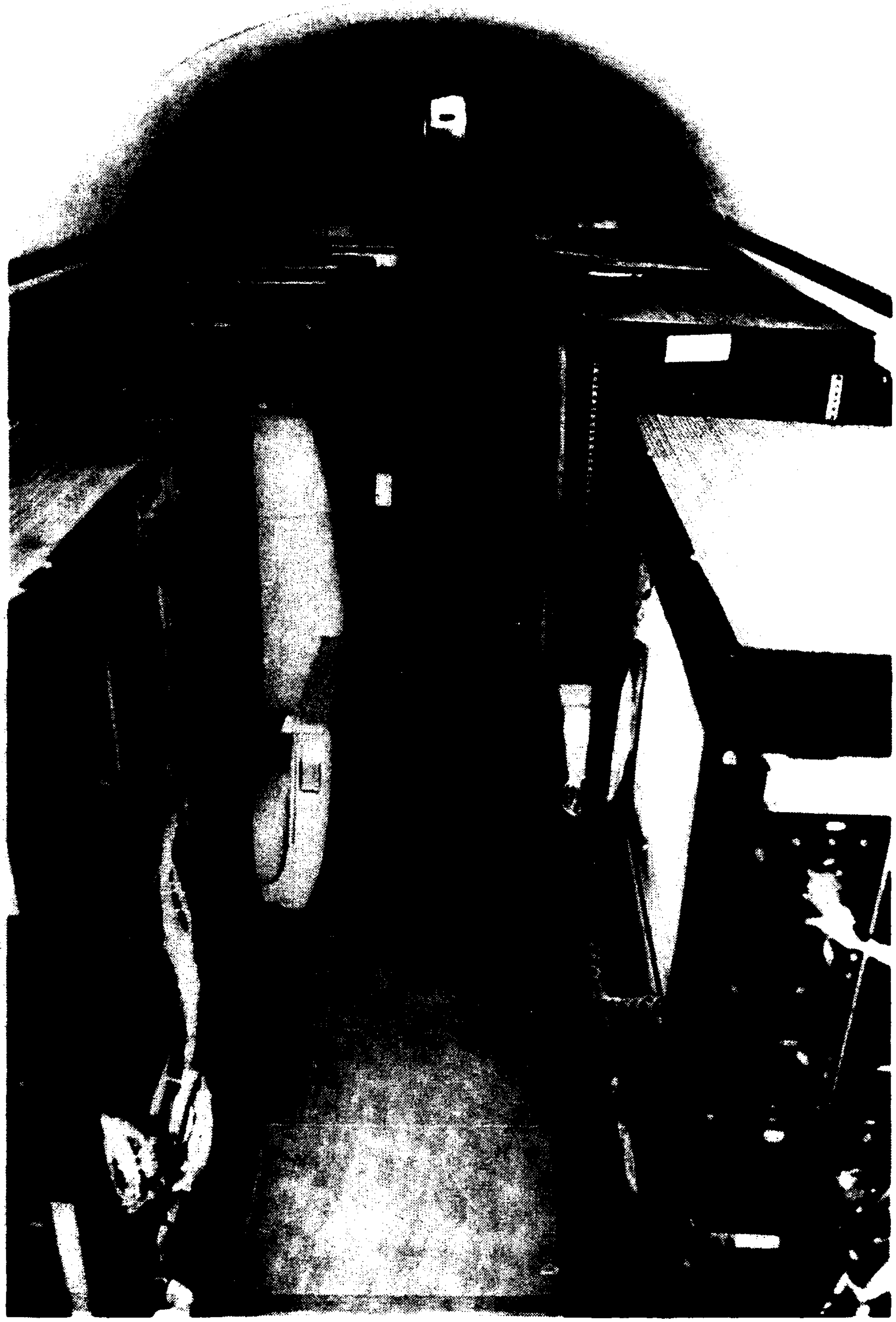


Figure E-18. Cabin Racks

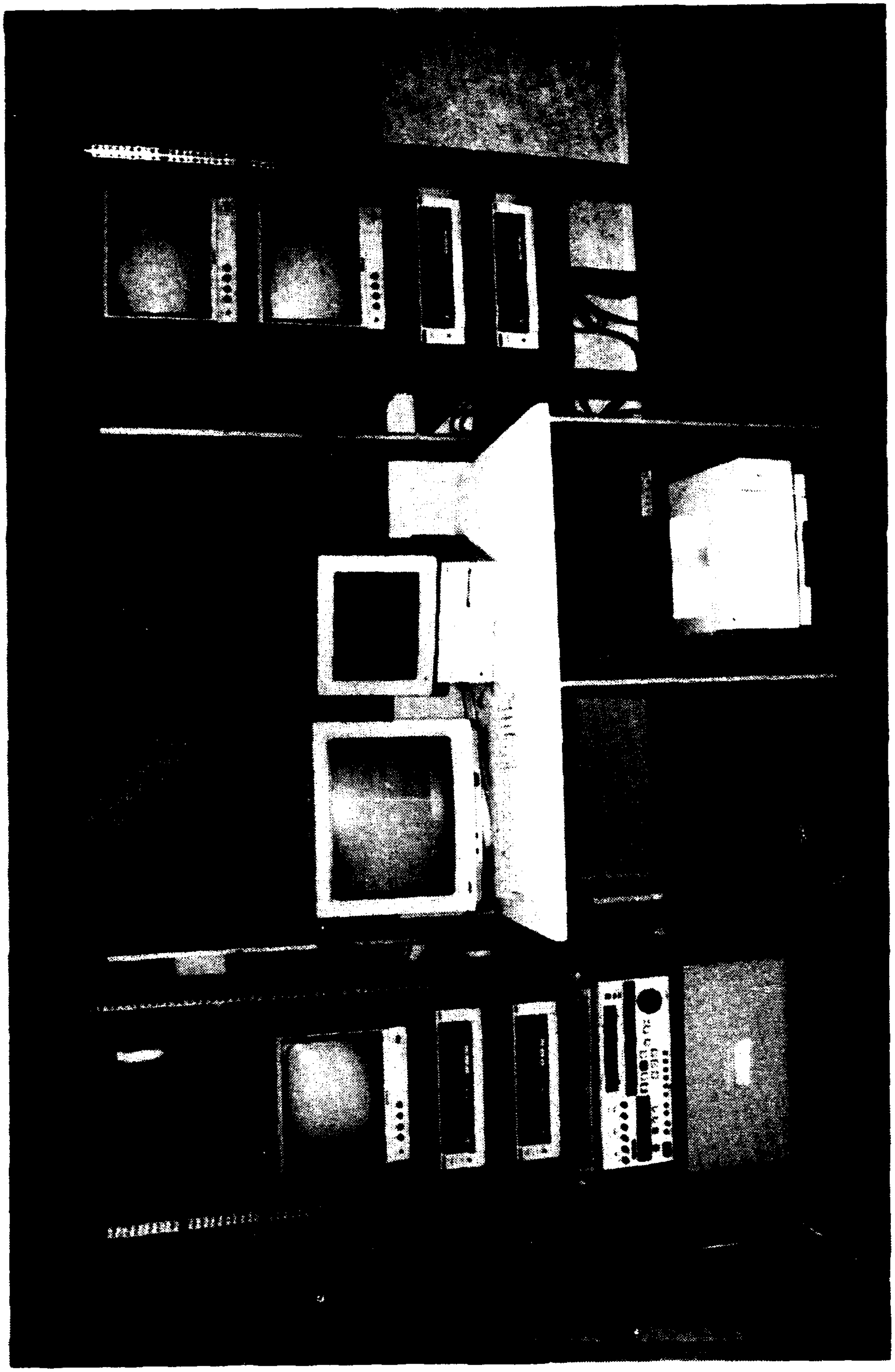


Figure E-19. Data Analysis Ground Station

APPENDIX F

FLIGHT TEST PLAN
FOR
THE SYNTHETIC VISION TECHNOLOGY
DEMONSTRATION PROGRAM

Appen

TRW Avionics & Surveillance Group
Military Electronics & Avionics Division
One Rancho Carmel, San Diego, CA 92128
Cage Code: 65409

SVSTD

Test Plan for the Synthetic Vision Technology Demonstration Program
CDRL X012

Date: 14 March 1992

No: D1-6056
Rev: -

Approval Signatures:

Prepared by: Roger H. Hoh - TRW Test Director

Approved by: Richard Tucker - TRW Program Manager

Concurrence by: Joseph McGuire - Raleigh Jet

Concurrence by: Malcolm Burgess - Synthetic Vision System Program Office

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TEST PLAN FOR THE SYNTHETIC VISION SYSTEM TECHNOLOGY DEMONSTRATION PROGRAM

March 16, 1992

I. OBJECTIVES

The objectives of this test plan are to:

- Provide a detailed test matrix and schedule to accomplish the combination of operational scenarios, experiments, and weather conditions specified in the Program Plan.
- Identify priorities to serve as a guide for day-to-day testing
- Assign personnel and organizations to be accountable for each component of tests
- Identify required resources for each test
- Provide an in-flight demonstration of current technology to industry and government representatives

II. SCOPE

This test plan describes the methods and procedures that have been developed to conduct flight testing of two millimeter wavelength sensors (35 Ghz and 94 Ghz), and one FLIR sensor. The output of these sensors will be presented to the pilot in a raster format on a head-up display (HUD), and will be superimposed on the usual symbology required for flight guidance. Testing will initially be done in clear weather, and will progress to include conditions that are consistent with Category I ILS minimums, and finally to Category II and Category III ILS minimums. Plans are to conduct tests that will include flight in different types of fog, and in rain. The achievement of these objectives will require accurate weather forecasting, rapid deployment capability, and a reliable system of sensors, pilot displays, and data acquisition equipment. Once an area of fog or rain consistent with the minimums specified in the test matrix (Section V) has been identified, it will be necessary to ferry the test aircraft to that location. The cost of such travel will be traded off with the alternative of obtaining more data in less interesting conditions. If the system performance and pilot workload are such that the team feels it will be safe to continue to below Cat I minimums, the policy will be to accept fewer approaches to obtain data in actual low visibility conditions. It is recognized that the inaccuracies associated with forecasting may make it impossible to complete the test matrix in a 270 hour test program. The established priorities will strongly impact what tests are accomplished. The following priorities have been established.

Group I Priorities

- Visibility (RVR)
- Weather Conditions (rain, rain-rate, different types of fog)
- Airport Surfaces
- 0/0 landings in simulated IMC
- Runway Incursions

Group II Priorities

- Glide-path intercept altitude (MDA for non-precision approaches)
- ILS guidance cutout - loss of flight director guidance between Cat I minimums and the initiation of flare. Nominally, there will always be flight director guidance in the flare.

Group III Priorities

- Day vs. night comparisons in identical weather conditions
- Approach offset angle
- Head down display
- Flare on flight path vector cue (no flight director in the flare)

Two millimeter wave radar (MMW) sensors will be tested, one at 35 Ghz and the other at 94 Ghz. Approximately 220 hours of flight time will be accomplished with the 35 Ghz sensor over a period of 4 calendar months. Approximately 50 hours of flight time will be allocated to testing the 94 Ghz sensor. These tests will be conducted as a permutation of the 35 Ghz MMW tests to determine the performance of this wavelength. Specifically the effects of weather, airport surface, and inherent resolution will be investigated. A forward looking infrared sensor (FLIR) will be operational in parallel with both sensors, i.e., there will always be two operational sensors in the radome. Quantitative data will be collected for both sensors on all runs. The selection of the sensor to supply the raster information on the HUD will be made by the pilot by way of a button on the control yoke. The planned strategy will be to use the millimeter wave sensor at longer ranges, switching to the FLIR on short final. This is based on expected limitations and strengths of each sensor. That is, MMW tends to have somewhat degraded resolution, and good penetration through visible moisture, whereas the FLIR is expected to have better resolution but is limited in its ability to penetrate weather. Some runs will be made using only MMW or FLIR for the entire approach to obtain baseline data. The MMW/FLIR switching strategy will be modified if necessary, based on initial flight experience with the sensors during the shakedown flights.

Some flights will be made to demonstrate the system to industry and government representatives. Since the demonstration pilot will occupy the right seat (normally occupied by the evaluation pilot), it will be necessary to have a qualified G-II pilot in the jump seat. Aircraft performance data and subjective pilot rating data will not be taken during these flights. Non-flying observers will be allowed on data flights only if escorted by a member of the SVSTD team that is not required to perform as a crew member. The minimum crew for data flights will consist of the safety pilot, evaluation pilot, test director, test engineer, and an MMW engineer.

The testing must be completed by the end of October 1992 to stay within cost on the aircraft lease.

III MANAGEMENT APPROACH

The G-II aircraft will be modified at Midcoast Aviation in St. Louis Missouri. An experimental certificate will be obtained from the FAA Central Region to allow the performance of local flight testing to check out the installation. In addition, a ferry permit must be obtained from the Central Region to allow the test aircraft to be ferried to Van Nuys. Applications for these certificates will be made by Midcoast. They will follow-up on any modifications deemed necessary by the FAA, and will be responsible for obtaining the experimental and ferry certificates. An experimental certificate to allow operations from Van Nuys will be issued by the Van Nuys Manufacturing Industry District Office (MIDO). This effort will be coordinated by Raleigh Jet, and they will arrange and supervise any modifications deemed necessary by the VNY MIDO. Day-to-day operations of the aircraft will be coordinated between Raleigh Jet and the TRW Flight Test Director with guidance from the TRW management and the Synthetic Vision Program Office (SVPO).

Approval to conduct testing below published IFR minimums will be applied for by the SVPO to FAA AFS 1. The Flight Test Plan and the Safety Plan will be presented as the rationale to allow such testing. Decisions to continue to lower weather minimums will require 100% agreement by Raleigh Jet, the Test Director, and his advisers. The decision of this group will be reviewed by the SVPO and TRW management. Both must be satisfied that the tests can be safely conducted before proceeding to lower minimums.

Approval to operate at specific airports will be obtained from the airport manager, ATC, and the FCC (approval to operate the active MMW radars) by the SVPO. Presentations will be made to each of the airport managers in the Van Nuys operating area by a team consisting of the SVPO, the Test Director, and a local FAA representative. Approvals for operations to more distant airports will be sought after sufficient experience has been gained to instill confidence that operations to low minimums are possible.

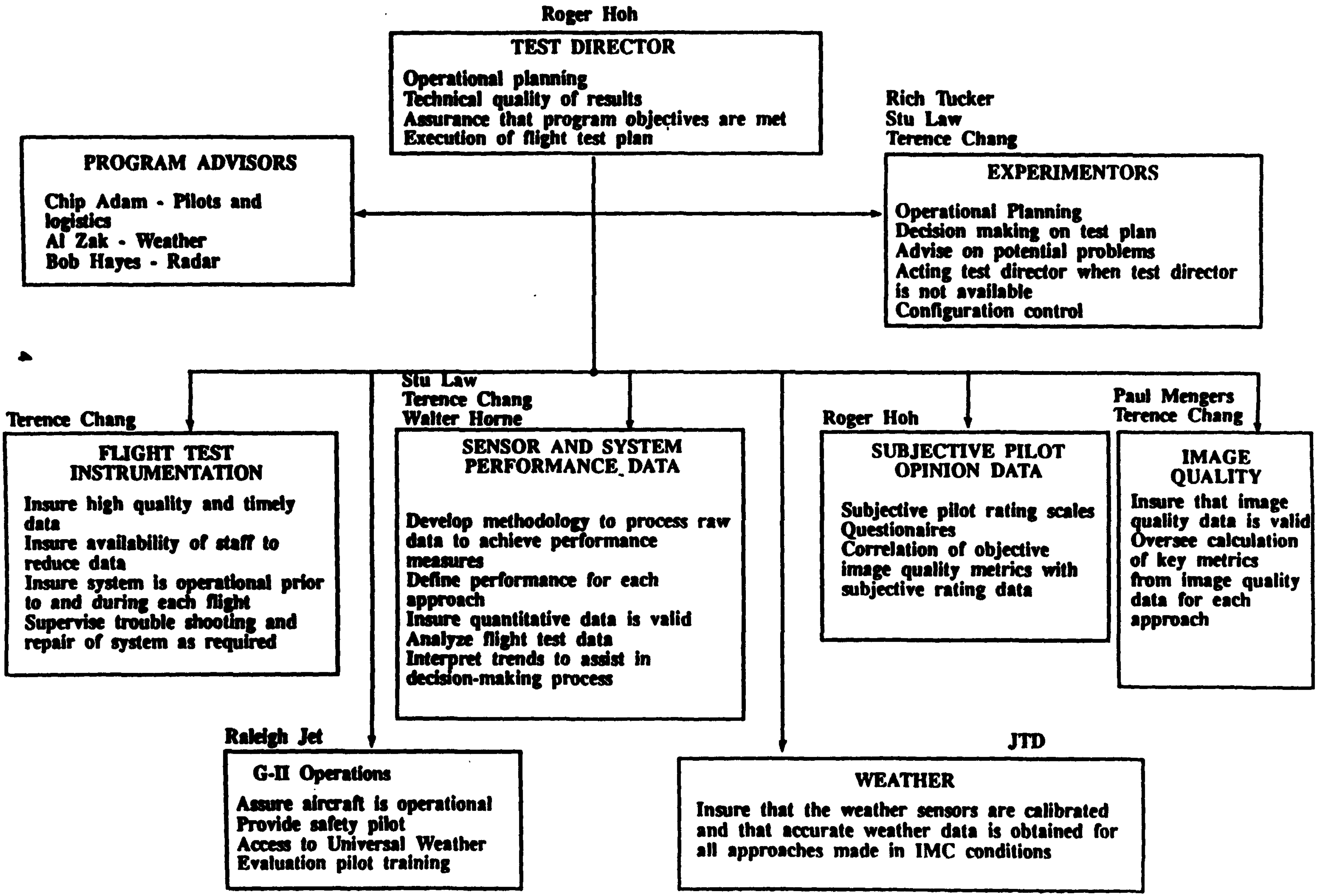
As the prime contractor, TRW will have the primary responsibility for the safe operation of the G-II aircraft. Efforts to insure that the tests are carried out safely consist of the development of a Safety Plan, and the presentation of the program to a Flight Readiness Review Board. This board will consist of expert advisers selected from NASA, industry, and the FAA. TRW will consider the advice of this board, as well as from Raleigh Jet, Midcoast, and the SVSTD team in making the final decision to conduct flying operations.

Operational areas of responsibility are detailed in Figure 1.

IV. TECHNICAL APPROACH

The testing shall be conducted according to the test matrices and schedule presented in Section V. The sequence of testing is based on a combination of satisfying the priorities outlined in Section II, and the development of an experience base upon which to base a decision to continue testing to lower minimums.

FIGURE 1. OPERATIONAL AREAS OF RESPONSIBILITY



1. **Shakedown Flights (35 Ghz MMW and FLIR)**

Shakedown flights will be conducted in visual flight rules (VFR) conditions (1000 overcast and 3 miles visibility). These flights will be conducted with one evaluation pilot, and the objective is to insure that the sensors and data acquisition system are working well enough to begin collecting data. A list of squawks will be generated during each shakedown flight, and the action to be taken to resolve each item on this list will be assigned during the debrief. In addition, the operational procedures developed in the simulator will be refined, and if necessary revised, during the shakedown flight. This will include the procedures and criteria that guide the pilot selection of sensor information (MMW or FLIR) to be presented on the HUD. This procedure will depend strongly on the quality of the MMW and FLIR images; information that will not be available until actual flying is initiated.

2. **Baseline Flights (35 Ghz MMW and FLIR)**

Following successful completion of the shakedown flights, data flights will be initiated with each of the three pilots in visual meteorological conditions (VMC). For this project, VMC will be defined as a ceiling of no less than 500 feet, and a visibility of no less than one statute mile. This is felt to be adequate for safety pilot monitoring during the early stages of the program. The evaluation pilot will fly these "baselining" flights in simulated IMC conditions to Cat II and Cat IIIc minimums. Simulated IMC flight will be accomplished with a system of shutters mounted on the evaluation pilots windscreen. These shutters can be adjusted so that the safety pilot can see through the right windscreen, but the evaluation pilot cannot. Upon successful completion of the VMC flights, ILS approaches will be made to values of RVR between 3000 feet and 1800 feet (Cat I minimums). The baselining flights will include non-precision approaches that will be flown to simulated Cat I minimums, in weather that is VFR. All non-precision approaches will be flown using a facility with an operating ILS to allow safety pilot monitoring of glideslope tracking. Approaches will not be made that include descents below the published MDA unless the safety pilot glideslope is on scale, and is not rapidly diverging. The feasibility of maintaining this accuracy (using only the flight path symbol and the synthetic runway) will be determined during these VFR baselining flights. These results will form the basis for a decision to test, (or not to test) non-precision approaches in real weather conditions, later in the program.

Calibration flights will be made to airports with five different surfaces in VMC conditions during the baselining flights. Such flights will be made with corner reflectors that are strategically located near the runway to define the radar cross section. GTRI will specify the exact dimensions and locations of these reflectors. During later testing, additional calibration flights will be made in low visibility conditions.

Ground operations using the synthetic vision image on the HUD and on the head down display (HDD) will be tested during taxi operations associated with each sortie. Since the evaluation pilot does not have the tiller (for low speed steering) such operations will be confined to gentle maneuvering (with rudder pedals) and identifying key objects in the field of view (intersections, other aircraft, etc.).

3. Approaches to Below Minimums (35 Ghz MMW and FLIR)

After at least one of the evaluation pilots has completed the baselining flights, a decision will be made to continue to lower minimums in actual weather conditions. If this decision is affirmative, a search will be initiated to find conditions where the RVR is less than 1800 feet. Current plans are to conduct this search along the California coast to take advantage of the early morning stratus. If this is unsuccessful, the search will be expanded to include Oregon, Washington, British Colombia, and Alaska. Extended trips will only be made after two pilots have completed the baseline matrices. This is based on a ground rule that low visibility approaches will not be made by any pilot that has not completed the baseline cases, and that two evaluation pilots will be carried on all data taking sorties. Two pilots are required to allow longer sorties (five hours nominal) to minimize the overhead associated with ferry to and from the test sites. One trip is planned to the east coast to take advantage of extensive fog that forms along the coast of Maine, and to conduct demonstration flights in the Washington area.

If non-precision approaches are feasible (acceptable safety pilot monitoring), they will be conducted on a non-intrusive basis with the ILS approaches to low minimums. For example, if while making approaches to low minimums, the visibility increases to above Cat I, non-precision localizer approaches will be initiated to fill in empty portions of the test matrix.

Ground operations using the synthetic vision image on the HUD, and on the head down display (HDD) will be tested during taxi operations in conditions of reduced visibility. Since the evaluation pilot does not have the tiller (for low speed steering) such operations will be confined to gentle maneuvering (with rudder pedals) and identifying key objects in the field of view (intersections, other aircraft, etc.). In conditions of severely reduced visibility, the evaluation pilot will assist the safety pilot in maintaining orientation on the airport. However, because the evaluation pilot does not have a steering tiller, taxi operations will only be conducted in conditions where the safety pilot can see well enough to navigate on the ground.

4. Shakedown Flights (94 Ghz MMW)

Testing with the 35 Ghz MMW and the FLIR is scheduled for completion by the end of the third week in August. One week has been allocated to installation of the 94 Ghz sensor. Shakedown flights will be conducted in visual flight rules (VFR) conditions (1000 overcast and 3 miles visibility). These flights will be conducted with one pilot, and the objective is to insure that the sensors and data acquisition system are working well enough to begin collecting data. A list of squawks will be generated during each shakedown flight, and the action to be taken to resolve each item on this list will be assigned during the debrief.

5. Baseline Flights (94 Ghz)

Following successful completion of the shakedown flights, data flights will be initiated with two evaluation pilots in visual meteorological conditions (VMC). The evaluation pilots will fly these "baselining" flights in simulated IMC conditions to Cat II and Cat IIIc minimums. Upon successful completion of the VMC flights, ILS approaches will be made to values of RVR between 3000 feet and 1800 feet (Cat I minimums).

Calibration flights will be made to airports with five different surfaces in VMC conditions during the baselining flights. Such flights will be made with corner reflectors that are strategically located near

the runway to define the radar cross section. GTRI will specify the exact dimensions and locations of these reflectors.

Ground operations using the synthetic vision image on the HUD and on the head down display (HDD) will be tested during taxi operations associated with each sortie. Since the evaluation pilot does not have the tiller (for low speed steering) such operations will be confined to gentle maneuvering (with rudder pedals) and identifying key objects in the field of view (intersections, other aircraft, etc.).

6. Approaches to Below Minimums (94 Ghz MMW)

After at least one evaluation pilot has completed the baselining flights, a decision will be made on whether to continue to lower minimums in actual weather. If this decision is affirmative, a search will be initiated to find conditions where the RVR is less than 1800 feet. Current plans are to conduct this search along the California coast to take advantage of the early morning stratus. If this is unsuccessful, the search will be expanded to include Oregon. Two evaluation pilots will be carried on all data taking sorties. Two pilots are required to allow longer sorties (five hours nominal) to minimize the overhead associated with ferry to and from the test sites.

7. Demonstration Flights (All sensors).

Demonstration flights will be conducted throughout the program, depending on the test schedule and the availability of the demonstration pilots. Only sensor data will be obtained on these flights. They will be conducted in VFR conditions.

8. Runway Incursions and Obstacle Identification (All Sensors).

On some runs, staged runway incursions will be accomplished to determine if the sensor is capable of alerting the pilot to such a hazard. These will be accomplished with an automobile equipped with two-way communications capability with ground control. The safety pilot will be aware of when such incursions will occur, and will execute a go-around if the evaluation pilot does not do so.

During non-precision approaches it will be desirable for the evaluation pilot to correctly identify obstacles on the approach path. The evaluation pilot will be asked to identify all obstacles that he can identify during every approach, and especially during non-precision approaches.

9. Special Resource Requirements

Some runs will require special resources. The calibration runs will require that the corner reflectors be carried on the aircraft to the test site. Runs in very low visibility may require that an additional team member be located at the test airport to observe the visibility at the approach end of the active runway. This will only be done if the accuracy and number of transmissometers does not meet the requirements for Cat II or Cat III as appropriate. It may also be necessary to assign one individual to keep traffic away from the glideslope antenna during approaches in very low visibility. This role may be allocated to the ground controller if a control tower is in operation.

V. TEST MATRIX

A. Introduction

The test matrices in this section of the Test Plan are based on priorities that have been established by the SVSTD team (see Section II) and will guide the testing throughout the program.

A schedule indicating each of the objectives of the test matrices, and the budgeted flying hours plotted against time is given in Figure 2. The horizontal bars in Figure 2 indicate the objective to be accomplished during each period, and include the estimated number of data runs, sorties, and flight hours required. As the project progresses, the bars will be filled by an amount proportional to the percentage of the test matrix that has been completed for that objective. A dashed line will be plotted to indicate the status of actual vs. projected flying hours. A measure of the success of the program will be to have the actual and projected flying hours coincide, and to have the bars filled up to the current date. The wide shaded lines indicate an estimated maximum amount of useful flying hours per month that can be accomplished. If the dashed line (line of actual flying hours) crosses this boundary, it is an indication that time is running out. Such a trend toward this boundary will result in an expanded weather search. For example it may be necessary to travel to the east coast, Iceland, or Alaska if extensive low clouds and fog are forecast for those areas, and time is running out. The planned tradeoff is to expend flying hours to achieve a reduced (but more interesting) matrix, rather than stay local and conduct repeat runs in the same conditions.

Some test conditions that have been judged to be low priority have not been included explicitly in the test matrices. For example night is only listed once, and crosswinds and offset approaches are not listed at all. It is assumed that approaches will be made during the night and day depending on the available weather, which has a much higher priority. For example, the fog rolls in along the California coast after midnight and burns off during the morning hours. It may be necessary to test between 0200 and 0700 to obtain the desired conditions of low ceilings and reduced visibility. Crosswinds will be flown as they occur. Similarly, angled approaches will flown only as they occur naturally during the non-precision, no-nav-aid approach procedure.

B. Shakedown and Baselining Flights for 35 Ghz MMW and FLIR

Shakedown flights will begin after the aircraft reaches Raleigh Jet and has completed ground testing of the HUD, Data Acquisition System, and Weather Pod as detailed in Section VI of this Test Plan. Ten hours of flight time have been allocated to system shakedown. This assumes that the inevitable problems associated with any new system will occur, and that each flight will result in a squawk list that will be resolved before initiating the next flight. Each flight will be conducted as a dry run of an actual data sortie to a local airport (e.g., Pt Mugu, Vandenberg, Santa Maria, etc.). Following each shakedown flight, data reduction will be carried out to refine procedures, obtain initial results on system performance, and identify problems. It is estimated that the shakedown flights will involve 5 two hour sorties, 20 approaches, and approximately two calendar weeks.

The baselining flights will begin as soon as all identified problems have been satisfactorily resolved. This will be decided by the test team, where Raleigh Jet will have the last word on safety, and the Test Director will provide the go-ahead related to system performance, with concurrence of the SVSTD test team, TRW management, and the SVPO. The objective of the baselining flights will be to

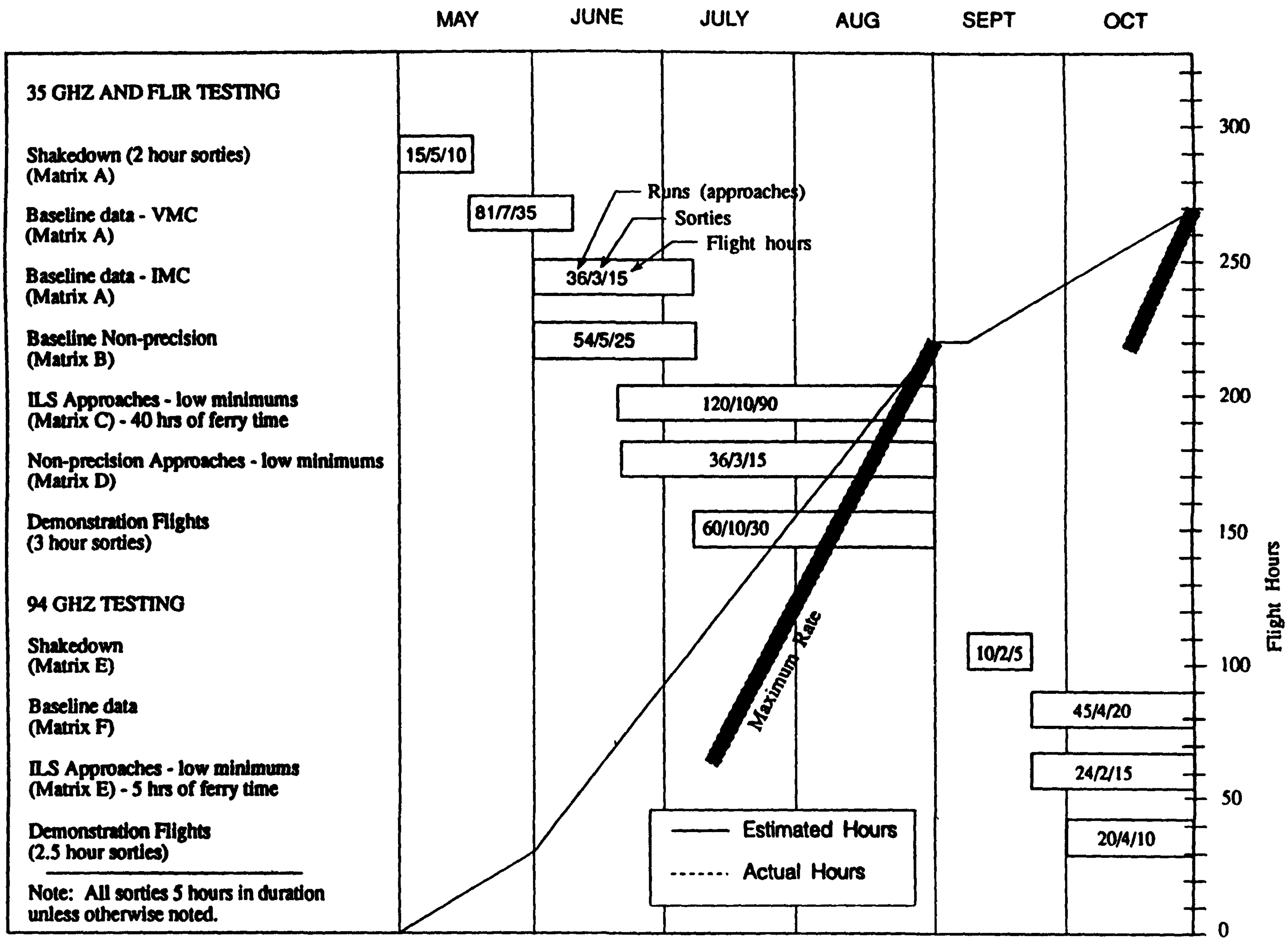


FIGURE 2 SCHEDULE OF FLIGHT HOURS AND TEST MATRIX COMPLETION

collect data in VMC conditions and in IMC conditions at or above standard Cat I ILS minimums (RVR between 1800 and 3000 ft). The purpose of these flights will be to expose all the evaluation pilots to the system in the real flight environment, develop confidence in the system, and to obtain sensor data in good weather for five different airport surfaces.

All data collection sorties are planned to be 5 hours in duration, of which 4 hours will be devoted to taking data. One hour has been allocated to ferry the aircraft to and from the test sites. The schedule for baselining therefore requires that all runs be made at an airport no greater than 0.5 hour range from VNY. Experience indicates that we can accomplish three approaches per hour, so that 12 approaches will be planned for each sortie. Shorter sorties will reduce the average number of approaches that can be conducted per flight hour, so there will be an emphasis on conducting sorties that are at least five hours in duration. The baseline flights are expected to include 117 ILS approaches. On the basis of the above assumptions this will require 10 sorties and 50 flight hours. In addition, 27 non-precision localizer-only approaches, and 27 non-precision no-Nav-Aid approaches will be flown. This will require 5 sorties and 25 flying hours. The planned schedule for these flights is shown in Figure 2. Two evaluation pilots will be carried on all sorties, and each pilot will fly for approximately 2 hours. The baselining will be accomplished for ILS approaches first to take advantage of reduced visibility conditions that may become available early in the program. The test matrices for the shakedown flights, and the baselining of precision and non-precision approaches are given in Tables 1 and 2.

Eighty-five total hours are estimated to complete the shakedown and baselining flights, and 30 hours of demonstrations are planned. Fifteen hours have been budgeted for non-precision approaches in visibilities that are less than one mile, but above Cat I ILS minimums. That leaves 90 hours to find visibilities below 1800 RVR (40 hours) and conduct approaches (50 hours). If it is obvious that the flying hour budget will be exceeded during VMC testing, runs will be eliminated to preserve the 90 hours set aside for low visibility operations.

Column five of Table 1 includes MMW calibration runs to each of the five airport surface types. These runs will include laying out two corner reflectors per specifications developed by GTRI. Since the data is provided for radar calibration, only one pilot will fly these runs. Three runs will be made to insure that the data is of sufficient quality, and is repeatable.

Table 1. Test Matrix A - Shakedown and Baseline ILS Approaches (35 Ghz MMW and FLIR)

Airport Surface Category	Description	Example	Shakedown Flights	Baseline Flights		
			VMC Conditions	VMC Conditions (Simulated Cat II)	VMC Conditions (Simulated 0/0)	IMC Conditions (RVR between 1800 and 3000 ft)
Apt A	Asphalt and grass	NTD, SMX, MRY, ACV, VNY,	1 pilot × 10 runs (10 runs)	3 pilot × 3 runs 3 pilot × 3 run (go around) (18 runs)	3 pilot × 3 runs 3 pilot × 3 runs (FLIR only) 3 pilot × 3 runs (MMW only) 3 pilot × 3 runs (HDD only) (36 runs)	3 pilot × 3 runs (day) 3 pilot × 3 runs (night) 3 pilot × 3 runs (FLIR only) (27 runs)
Apt B	Concrete and grass	VBG,	1 pilot × 5 runs (5 runs)	3 pilot × 3 runs (9 runs)	3 pilot × 3 runs (9 runs)	3 pilot × 3 runs (9 runs)
Apt C	Grooved asphalt and grass	SBA		1 pilot × 3 runs (3 runs)		
Apt D	Grooved concrete and grass	LAX		1 pilot × 3 runs (3 runs)		
Apt E	Grooved asphalt and concrete	SAN		1 pilot × 3 runs (3 runs)		

Notes:

1. Simulated Cat II approaches will be conducted by restricting the evaluations pilot's outside view until the aircraft is within 1200 feet of the end of the runway. Simulated 0/0 will be conducted by restricting the pilot's outside view throughout touchdown and rollout.

2. The evaluation pilot will leave the raster on through the flare and touchdown for the simulated Cat II and simulated 0/0 flights. He will be allowed to select raster on or off during the flare for all other flights. If problems are encountered with flaring with the raster on that do not allow a safe landing, the pilot will be allowed to de-select the raster for future landings, and the problems will be noted as being significant and limiting.

3. Go-arounds will be briefly investigated to determine if there are any unique problems associated with SVS. These cases will coincide with staged runway incursions, and will be presented randomly to the pilot. Such occurrences will consist of driving a vehicle onto the runway while the test aircraft is on final approach. This will be carefully coordinated with the airport manager, and the tower, and the vehicle being driven onto the runway will be in two-way communications with ground control. If the pilot does not see the object on the runway on short final, and initiate a go-around, the safety pilot will call for a missed approach.

4. Unless otherwise noted, the sensor displayed to the pilot will be the 35 Ghz MMW during the approach. The pilot will be instructed to switch to FLIR on short final. Some runs will be made with only FLIR or with only MMW to obtain baseline data.

5. Pilots will fly approaches to actual Cat I minimums only after flying approaches to simulated Cat II minimums in VMC conditions. For this program visual meteorological conditions will be considered as an overcast of no less than 500 feet and a visibility no less than 1 mile.

6. Corner reflectors will be placed near the runway for three approaches to one airport in each of the five categories, A through E above. This will be accomplished during the shakedown flights, and the baseline flights under simulated Cat II conditions. The reflectors will be strategically placed by GTRI, or by using detailed instructions from GTRI.

Table 2. Test Matrix B - Baseline Non-Precision Approaches (35 Ghz and FLIR)

Description of Approach	Simulated Cat I in conditions greater than 1000 overcast and visibility greater than 3 miles	Simulated Cat IIIb in conditions greater than 1000 overcast and visibility greater than 3 miles
Localizer (no glideslope information on evaluation pilots displays)	3 pilots × 3 runs (9 runs)	3 pilots × 3 runs 3 pilots × 3 runs (FLIR) (18 runs)
Localizer up to 4 km, then no navigation data.	3 pilots × 3 runs (9 runs)	3 pilots × 3 runs 3 pilots × 3 runs (FLIR) (18 runs)

C. Runs in Low Visibility Conditions with 35 Ghz MMW and FLIR

Of the 90 hours available for runs in low visibility conditions, it is assumed that 40 hours will be required to ferry the aircraft to sites forecast to provide the required low visibilities. That leaves 50 hours of actual approaches in very low visibility conditions. While this amounts to a significant overhead, it is felt that even a few successful approaches in Cat II and Cat III visibility conditions would significantly enhance the results of the project. The 50 hours of data flying is predicted to result in 120 approaches in very low visibility conditions. A matrix of test conditions for these approaches is given in Table 3. Most approaches will be made in fog as it is considered unlikely that the RVR will be less than 1100 feet in rain alone. RVR conditions below Cat I minimums are reasonably rare, and it is likely that significant ferry time may be expended in trying to find these low values of visibility during the summer months when the tests will occur. It is therefore important to realize that Table 3 represents a target for planning purposes, and that it will probably be necessary to tradeoff ferry time to travel to a location where the desired weather exists. Travel to remote locations will only be accomplished if we approach the shaded regions of the Figure 2 schedule.

The process of expanding the envelope from Cat I to Cat II, and finally Cat IIIa and Cat IIIb is outlined in Section VIII.

Table 3. Test Matrix C - ILS Approaches in Very Low Visibility Conditions (35 Ghz and FLIR)

Airport Type	700 ≤ RVR ≤ 1200		1200 < RVR < 1800	
	Fog	Rain	Fog	Rain
A or B	3 pilots × 3 runs 3 pilots × 3 runs (FLIR) 3 pilots × 3 runs (MMW) (27 runs)		3 pilots × 3 runs 3 pilots × 3 runs (FLIR) 3 pilots × 3 runs (MMW) (27 runs)	3 pilots × 3 runs 3 pilots × 3 runs (FLIR) 3 pilots × 3 runs (MMW) (27 runs)
C or D	3 pilots × 3 runs (9 runs)		3 pilots × 3 runs (9 runs)	3 pilots × 3 runs (9 runs)
A	1 pilot × 3 runs (Calibration)			
B	1 pilot × 3 runs (Calibration)			
C	1 pilot × 3 runs (Calibration)			
D	1 pilot × 3 runs (Calibration)			

Notes:

1. Unless otherwise noted, the pilot will select the best sensor during the approach - nominally MMW at longer ranges, and FLIR close to the Flare and landing. A notation of one type of sensor indicates that the entire approach will be made with that sensor selected on the HUD.

2. It will be desirable to conduct approaches to different airport surfaces in very low visibility conditions. Surfaces A and B tend to be the most common (Asphalt and grass, and concrete and grass respectively). Therefore, these are specified as the baseline conditions upon which to obtain runs to compare MMW and FLIR. Runs at airport surfaces C and D will have a lower priority. Calibration runs will be made at all airport surface types in low visibility conditions, if the needed weather can be found. This data will be used for comparison with the calibrations accomplished in Matrix A.

3. Once a desired visibility condition is found, the testing of different sensors will be accomplished back to back (e.g., a MMW run followed immediately by a FLIR run). The runs will be conducted this way until each pilot has three runs in each condition. This sequence is not ideal from a human factors data standpoint, but is considered essential to obtain a comparison of sensors in identical weather conditions.

The following test matrix illustrates the plan to execute non-precision approaches in actual weather conditions. The objective of this phase of the project is to investigate the extent to which approaches can be performed to minimums lower than the non-precision minimum descent altitude (MDA). This will only be done at an airport with an ILS or GCA backup to provide the safety pilot with precision glideslope information. The feasibility of maintaining a three degree glideslope using only HUD SVS guidance (flight path vector and three degree reference superimposed on the touchdown zone of the runway image) with sufficient accuracy to keep the real glideslope within 1.5 dots will be investigated during the base runs. If this cannot be done the following matrix will not be attempted. A second objective of the non precision approach task is to determine the extent to which the evaluation pilot can see obstacles (using the SVS raster display on the HUD) while descending on the final approach.

Table 4. Test Matrix D - Non Precision Approaches to Cat I Minimums (35 Ghz and FLIR)

Description of Approach	Visibility below 1 mile and ceiling below MDA for approach
Localizer (no glideslope information on evaluation pilot displays)	3 pilots × 3 runs 3 pilots × 3 runs (FLIR) (18 runs)
Localizer up to 4 km, then no course or glideslope information on evaluation pilot displays. (Pilot will use SVS image and HUD flight path symbol for course and glidepath guidance). Distance information will be displayed to the evaluation pilot, if available.	3 pilots × 3 runs 3 pilots × 3 runs (FLIR) (18 runs)

This matrix will require 36 runs to complete. This will be accomplished in 3 sorties and 15 hours of flying time.

D. Shakedown and Baselining Flights with 94 Ghz MMW

Based on the Figure 2 schedule, testing of the 35 Ghz MMW and FLIR sensors will be completed by the end of August. At that time the 35 Ghz MMW will be removed and the 94 Ghz MMW installed. One week has been allowed for installation and ground checkout. The context of this testing will be to evaluate the 94 Ghz sensor and system performance. Tests already conducted, where radar performance is not an issue, will not be duplicated. An abbreviated run matrix of 50 hours will be available for testing this sensor. Of that, 5 hours will be budgeted for shakedown, 20 hours for baselining, 15 hours for approaches in very low visibility, and 10 hours for demonstrations. The matrix of runs for the shakedown and baseline flights is given in Table 5.

Table 5. Test Matrix E - Shakedown and Baseline ILS Approaches (94 Ghz MMW)

Airport Surface Category	Description	Examples	Shakedown Flights	Baseline Flights		
			VMC Conditions	VMC Conditions (Simulated Cat II)	VMC Conditions (Simulated 0/0)	IMC Conditions (RVR between 1800 and 3000 ft)
Apt A	Asphalt and grass	NTD, SMX, MRY, ACV, VNY,	1 pilot × 5 runs (5 runs)	2 pilot × 3 runs (6 runs)	2 pilot × 3 runs (6 runs)	2 pilot × 3 runs (6 runs)
Apt B	Concrete and grass	VBG,		2 pilot × 3 runs (6 runs)	2 pilot × 3 runs (6 runs)	2 pilot × 3 runs (6 runs)
Apt C	Grooved asphalt and grass	SBA		1 pilot × 3 runs (3 runs)		
Apt D	Grooved concrete and grass	LAX		1 pilot × 3 runs (3 runs)		
Apt E	Grooved asphalt and concrete	SAN		1 pilot × 3 runs (3 runs)		

Notes:

1. The evaluation pilot will leave the raster on through the flare and touchdown for the simulated Cat II and simulated 0/0 flights. The procedure for selecting FLIR for the flare will be the same as was used for the 35 Ghz sensor. If problems are encountered with flaring with the raster-on that do not allow a safe landing, the pilot will be allowed to de-select the raster for future landings, and the problems will be noted as being significant and limiting.

2. Pilots will fly approaches to actual Cat I minimums only after flying approaches to simulated Cat II minimums in VMC conditions. For this program visual meteorological conditions will be considered as an overcast of no less than 500 feet and a visibility no less than 1 mile.

3. Corner reflectors will be placed near the runway for three approaches to one airport in each of the five categories, A through E above. This will be accomplished during the shakedown flights, and the baseline flights under simulated Cat II conditions. The reflectors will be strategically placed by GTRI, or by using detailed instructions from GTRI.

E. Runs in Low Visibility Conditions with 94 Ghz MMW

Fifteen hours have been budgeted for low visibility runs with the 94 Ghz MMW. Ten of these will consist of sorties to collect data (see Table 6), and five hours are to ferry the aircraft to the low visibility conditions.

Table 6. Test Matrix F - ILS Approaches in Very Low Visibility Conditions (94 Ghz MMW)

Airport Type	$700 < RVR \leq 1200$		$1200 < RVR < 1800$	
	Fog	Rain	Fog	Rain
A or B	3 pilots × 3 runs (9 runs)		3 pilots × 3 runs (9 runs)	2 pilots × 3 runs (6 runs)

Notes:

1. It will be desirable to conduct approaches to different airport surfaces in very low visibility conditions. Surfaces A and B tend to be the most common (Asphalt and grass and concrete and grass respectively). Therefore, these are specified as the baseline condition upon which to obtain runs to compare with the 35 Ghz MMW.

2. Two pilots are specified because of time limitations associated with testing the 94 Ghz sensor.

VI. SYSTEM CHECKOUT PROCEDURES

An outline of the system checkout procedures is given in this section. Detailed checklists for these procedures are given in Appendix A.

A. Before Each Flight

1. While in Hangar

System checkout will begin 45 minutes prior to engine start using a ground AC power cart. The test engineer, MMW engineer, and weather engineer will be present. The checkout will be initiated by verifying that all main circuit breakers in the rear cabin are off, connecting the ground power cart, and turning on all of the main circuit breakers. The following subsystems will be checked by the Test Engineer.

1. Video subsystem
2. Data acquisition system
3. FLIR
4. HUD

The following subsystems will be checked by the MMW Engineer.

1. MMW sensor - verify image
2. Check video recorders
3. Check MMW data acquisition system

The following subsystems will be checked by the Weather Engineer.

1. Check all probes and remove protective covers
2. Check tape recorder
3. Calibrate all probes
4. Verify supply paper and tape

2. On Ramp With Left Engine or APU Running

The Test Engineer will verify that all main circuit breakers in the rear cabin are OFF prior to APU or left engine start (by a pilot or Raleigh Jet mechanic). Verify that the power converters are on after the APU or left engine are running, then turn on all main circuit breakers. The following subsystems will be checked by the Test Engineer.

1. Video - verify TV distribution
2. Data acquisition system
3. FLIR - verify image after 5 minutes
4. HUD - verify raster and stroke test patterns and calibrate with grey scale - check video select switch

The following subsystems will be checked by the MMW Engineer.

1. MMW sensor - verify image
2. Video recorders
3. MMW data acquisition system

The following subsystems will be checked by the Weather Engineer

1. Set breakers
2. Verify print parameters
3. Set time

B. After Each Flight

After landing and before engine shutdown, the test engineer shall insure that all main breakers are OFF, the AC power cart is connected, and that its power is turned ON. Upon completion, shutdown TD1, EN1, and DA2 racks and Camera, FLIR, and HUD. The MMW engineer will shutdown the EQ1 and SD3 racks. The Weather Engineer will perform a calibration of the weather acquisition system, shutdown the OB1 rack, and replace protective covers on all probes.

C. Before First Flight

The checkout procedures to be conducted before the first flight are essentially identical to those noted above. However, the procedure will be halted as problems are uncovered, and will be restarted when each problem is resolved. The system will be ready for first flight when all of the above checkout procedures can be successfully completed. This process is expected to require minimal trouble shooting because all the subsystems will have been checked out on the hot-bench at TRW.

VII. MISSION PLANNING AND PREFLIGHT COORDINATION

The tests will be conducted in accordance with the schedule shown in Figure 2, and the accompanying test matrices in Section V. During the first three weeks of testing, most flying will be done in VMC conditions. During the remainder of the program, the tests will be strongly driven by the available weather. The test director will use the following resources to determine the forecasted weather at SVS approved airports.

- FAA Flight service (telephone and direct user access terminal (DUAT))
- Universal weather service - telephone
- Jeppesen Weather Plan - current and forecast weather maps on computer.
- Military weather service at Vandenberg
- Direct telephone contact with control tower and other appropriate ATC facilities (by prior arrangement).

As the test matrices are completed, the required weather will consist of very low visibilities (Cat II and less) that are expected to be difficult to forecast and find. The test director will rely on the project meteorologist (Dr. Al Zak) to assist in checking forecasts of low visibilities in the contiguous United States, Canada, and Alaska. During the months of July and August the test team and two evaluation pilots will be on standby for immediate deployment to areas of forecast low visibilities. Each member of the test team will have a pager, and the Test Director will carry a Cellular Phone to insure 24 hour access. Personal leave (sickness, vacations, etc.) will be handled by having an backup person assigned for each function.

Approval to operate the MMW radar at all potential test sites will be obtained.

When an airport is targeted for testing, the airport manager, control tower, and local ATC facility will be notified of our intentions. If calibration runs or runway incursion tests are to be accomplished, these will be coordinated with the airport manager and the tower as soon as the decision is made to test at that airport. It may also be necessary to make special arrangements to keep traffic away from the glideslope antenna for operations in very low visibilities.

The decision to conduct a mission will be made when the following conditions are met.

- The weather conditions at an approved airport are consistent with the test objectives and location of the test aircraft.

- The aircraft, sensors, and data acquisition system are operational.

- The SVS crew and two evaluation pilots are available.

- Approval has been obtained from the airport manager.

VIII PROCEDURES

A. Test Procedures

The normal procedures for each sortie are summarized as follows.

- Complete mission planning, file flight plan, and obtain necessary weather briefings (Section VII).

- Contact crew members and evaluation pilots and advise of mission and times.

- Conduct mission brief one hour prior to takeoff

- Test Engineer, Sensor Engineer, and Weather Engineer conduct checkout in hanger while flight crew and Test Director review primary and alternate mission objectives. A final check of weather is also made at this time.

- Aircraft is rolled out of the hanger, and crew executes all required checklists.

- Evaluation pilot completes portions of ground test matrix during taxi to active runway (as briefed).

- Aircraft is flown to the test airport by the safety pilot.

- Execute pre-approach checklists

- Execute approaches. Each evaluation pilot will conduct 6 approaches (about two hours).

- Most approaches will be continued through touchdown and rollout. Depending on runway length, weather, and ATC, the safety pilot may execute a touch-and-go, or taxi back for takeoff. Prior coordination with ATC will prepare them for multiple approaches in actual weather conditions.

- While maneuvering for the next approach, the test team will execute the proper checklists to reset the instrumentation, and the test director will debrief the evaluation pilot using a voice recorder. The test director will also participate in the final checklist with the test team before executing the next approach.

- The test director will keep track of the weather trends at the airport of operation, and at the alternates, if conditions indicate that a change may be required (usually due to improving visibility). He may depend on the evaluation pilot not flying to assist in keeping track of weather.

- After each evaluation pilot has flown for two hours (approximately 6 approaches each), the aircraft will be flown back to the base of operations by the safety pilot. The evaluation pilot may conduct an approach to home base if so briefed.

- The evaluation pilot will perform the required ground evaluations during taxi.

- The test team will perform the shutdown checklist.

- The test director will conduct a post-flight briefing, outlining the days results, problems that need to be resolved, and plans for the next test.

The Detailed checklists for each crew-member are given in Appendix A. These checklists will be the same for each approach, to the extent possible. There will be some variations to account for differences in procedures for each type of approach.

B. Procedures To Go Below Cat I ILS Minimums

The process of expanding the envelope from Cat I to Cat II, and finally Cat III will be accomplished in small increments. Before continuing to Cat II, it will be necessary to have successfully and repeatedly completed approaches to 2400 RVR, and then to 1800 RVR. Since 1800 RVR requires centerline lighting and touchdown zone lights (TDZ/CL), it is effectively below Cat I minimums at all of the airports we will be operating at. Airports with TDZ/CL lighting are not practical test sites because they are either too far away, are not in a location where low RVRs are likely in the summer, and tend to be very busy (e.g., LAX, SFO, SAC). There are only 72 Type II and 39 Cat III runways in the U. S.

As long as the weather is above Cat I minimums, the safety pilot monitoring task is straight forward as he will have ILS raw data information that has been flight checked, and he will be operating in a well understood environment. The glideslope associated with Type I ILS beams are certified down to 100 feet as they are considered as a part of the missed approach procedure. This means that the safety

pilot will have accurate raw data glideslope information to at least 100 ft agl. Experience has shown that most glideslopes are actually good down to 50 ft agl. Localizer data is usually good enough to provide accurate touchdown and rollout guidance. The tendency of the glideslope signal to be affected by traffic near the antenna site is also a factor in the quality of the beam. Beams that are used for Cat II and Cat III are less susceptible to such disturbances, and the areas around them are marked as prohibited when Cat II or Cat III operations are in progress. The FAA flight check data for all of the ILS beams at the SVSTD test sites is being made available to the program. The decision to proceed below 2400 RVR to no less than 1800 RVR will require the following.

- Assurance that the glideslope is valid to at least 100 feet and preferably to 50 feet.

- Practice safety pilot takeovers and missed approaches have been safely accomplished and practiced in the Simuflight simulator. These will be initiated at the target DH (200 feet in this case). At least one such missed approach shall be accomplished by the safety pilot in the airplane.

- The evaluation pilot has successfully completed approaches to a 100 foot DH in simulated IMC conditions in the G-II aircraft.

Following successful completion of actual approaches in conditions of 1800 RVR, the next step will be to expand the envelope to Cat II minimums (1200 RVR and 100 foot DH). The decision to proceed below 1800 RVR to no less than 1200 RVR will require the following.

- Assurance that the glideslope is valid to at least 50 feet.

- Practice safety pilot takeovers and missed approaches have been safely accomplished and practiced in the Simuflight simulator. These will be initiated at the target DH (100 feet in this case). At least one such missed approach shall be accomplished by the safety pilot in the airplane.

- The evaluation pilot has successfully completed approaches to no higher than a 50 foot DH, and preferably to flare and touchdown (i.e., 0/0) in simulated IMC conditions in the G-II aircraft.

- An individual with two-way radio contact with the G-II is stationed near the runway threshold to insure that the visibility remains at or above the target value during the approach. This will be waived if at least 2 transmissometers are available (as required for normal Cat II).

The final step will be to proceed to Cat IIIa minimums (700 RVR and 50 ft DH). This will only be accomplished if approaches to Cat II minimums can be completed routinely. The decision to proceed below 1200 RVR to no less than 700 RVR will require the following.

- Assurance that the glideslope is valid to at least 50 feet.

- Practice safety pilot takeovers and missed approaches have been safely accomplished and practiced in the Simuflight simulator. These will be initiated at the target DH (50 feet in this case). At least one such missed approach shall be accomplished by the safety pilot in the airplane.

- The evaluation pilot has successfully completed approaches to flare and touchdown (i.e., 0/0) in simulated IMC conditions in the G-II aircraft.

- An individual with two-way radio contact with the G-II is stationed near the runway threshold to insure that the visibility remains at or above the target value during the approach. This will be waived if at least 3 transmissometers are available (as required for normal Cat III).

IX. CREW DUTIES AND COORDINATION

A detailed accounting of the activities of each crew member during each sortie is given below.

A. Prebrief - Conducted by Test Director
   1. Objectives of this sortie
   2. Planned approaches in order - identify appropriate test cards
   3. Alternatives if weather is different than forecast or if there are instrumentation problems.
   4. Evaluation pilot rotation during flight
   5. Review responsibilities of each crew member
   6. Review emergency procedures

B. Crew location in aircraft
   1. Safety pilot in left seat
   2. Evaluation pilot in right seat
   3. Test director will occupy both the jump seat to observe and interact with the evaluation pilot, and the test director station to observe data as required, and to interact directly with the test team.
   4. Test engineer at test engineer station
   5. MMW engineer at MMW engineer station
   6. Evaluation pilot not-flying at observer station at rear of aircraft. It is intended to keep the pilot not flying isolated from the pilot commentary and ratings to maintain experimental validity (independent results).
   7. Weather analyst at observer/weather station (only aboard for flights in IMC conditions)

C. Pre-taxi - in aircraft
   1. Safety pilot and evaluation pilot
      a. Pre-taxi checklist
      b. ATC clearance

2. Test Director
   a. Final check of weather before engine start (call tower at test site on cellular phone)
   b. Obtain clearance from test and sensor engineers that all systems and sensors are functional
3. Test Engineer
   a. Checkout instrumentation
   b. Advise test director of status
4. MMW engineer
   a. Checkout MMW and recording equipment
   b. Advise test director of status

D. Taxi operations on SVS
1. Safety Pilot
   a. Backup evaluation pilot, using tiller for steering
   b. Look for obstructions
2. Evaluation Pilot
   a. Select proper sensor (FLIR or MMW) - nominally FLIR during taxi
   b. Steer aircraft to extent possible with toe-brakes (will abandon this procedure if it results in excessive wear or overheating of brakes).
3. Test Director
   a. Note evaluation pilot comments
   b. Assist in looking for obstructions
4. Test Engineer
   a. Monitor video
   b. Monitor recording equipment
5. MMW Engineer
   a. Monitor image

E. Pre-takeoff checklists (See Appendix for detailed checklists)
1. Basic G-II
2. Evaluation pilot SVSTD system controls and sensors
3. Data acquisition system

F. Takeoff
1. Safety Pilot
   a. Provide directional control with tiller at low speed
   b. Monitor aircraft performance and takeover if necessary
   c. Takeover at 1500 ft. agl.
2. Evaluation Pilot
   a. Perform takeoff using SVS HUD display
   b. Take control of aircraft at 1500 ft. agl.
3. Test Director
   a. Take notes on performance and image (HDD)
   b. Take notes on pilot comments
4. Test Engineer
   a. Monitor data recording equipment
   b. Monitor image quality

5. MMW Engineer
    a. Monitor image quality
    b. Monitor radar recording equipment

G. Enroute
1. Safety pilot
    a. Review appropriate approach plates
    b. Review abort tolerances and procedures
    d. Fly airplane
    e. Look for traffic
2. Evaluation Pilot
    a. Review SVSTD approach plate and procedures
    b. Review questionnaire and rating scales
    c. Final checklist of SVSTD system
    c. Look for traffic
3. Test director
    a. Go over objectives with evaluation pilot
    b. SVSTD data system checklist
    c. Final check of weather at destination and alternates
    d. Look for traffic
4. Test engineer
    a. Final checks of data retrieval system
5. MMW engineer
    a. Final checks of sensor and data recording equipment

H. Transition enroute to approach
1. Safety pilot
    a. Fly aircraft to initial condition and turn over to evaluation pilot.
    b. Monitor aircraft position, attitudes and systems.
    c. Look for traffic
    d. Perform landing checklist
2. Evaluation Pilot
    a. G-II landing checklist with safety pilot
    b. Set HUD brightness and sensitivity controls for stroke and raster
    c. Final check of SVSTD approach plate and procedures
    d. Take control of aircraft at initial condition; usually two or three miles outside the final approach fix.
3. Test director
    a. Checklist items with evaluation pilot
    b. Checklist items with test engineer
    c. Checklist items with sensor engineer(s)
    d. Confirm run number with crew
    e. Look for traffic
4. Test engineer
    a. Perform final checklist with test director
    b. Perform system checklist

5. MMW sensor engineer
    a. Perform final checklist with test director
    b. Perform system checklist
6. Weather Analyst
    a. Insure weather pod is operational

I. Approach
1. Safety pilot
    a. Coordinate with ATC
    b. Look for traffic
    c. Monitor raw ILS or GCA information
    d. Monitor flight test frequency (ground personnel creating obstruction on runway or advising of changes in RVR). This frequency may be ground control.
    d. Take control and initiate abort if
        (1) established raw data limits are exceeded.
        (2) there is a traffic conflict
        (3) there are aircraft or data measurement system problems
        (4) there are obstructions on the runway and evaluation pilot does not initiate an abort
        (5) required for any reason deemed necessary by safety pilot
2. Evaluation Pilot
    a. Fly the approach as briefed
    b. Event markers at appropriate time
    c. Initiate a go-around if there are any obstructions on the runway
    d. Comments as workload and time permit
3. Test director
    a. Monitor approach and note all significant events
    b. Note pilot comments (voice recorder)
    c. Keep track of run numbers
    d. Look for traffic
    e. Assist safety pilot in monitoring flight test frequency
    e. Monitor weather at test site (and alternate if necessary) Use evaluation pilot not flying to assist with weather monitoring.
4. Test engineer
    a. Monitor on-line data
    b. Monitor raster output and note any discrepancies to test director
    c. Insure that all data tapes are running
    d. Monitor FLIR output
    d. Keep track of run numbers
5. MMW sensor engineer
    a. Monitor sensor output
    b. Advise test director if performance is degraded
6. Weather Analyst
    a. Insure weather pod is operational

J. Missed Approach (Initiated by Safety Pilot) - Also takeoff part of touch-and-go landing
  1. Safety Pilot
    a. Take over controls and fly missed approach procedure
  2. Evaluation Pilot
    a. Assist safety pilot as required
    b. Make comments related to last approach - tape recorded
  3. Test Director
    a. Take notes on evaluation pilot commentary and performance
    b. Prompt evaluation pilot as necessary
  4. Test Engineer
    a. Check run number and tape status
  5. MMW sensor Sensor Engineer and Weather Analyst
    a. Standby

K. Missed Approach (Initiated by Evaluation Pilot)
  1. Safety Pilot
    a. Monitor missed approach and takeover controls if necessary
    b. Takeover controls at 1500 feet and begin procedure to set up for next approach
  2. Evaluation Pilot
    a. Initiate missed approach if:
      (1) Obstructions are seen on the runway
      (2) Any unsafe excursions are encountered
      (3) The SVS image is lost when it is required for continued safe flight
    b. Fly missed approach procedure to an altitude of 1500 feet
    c. After 1500 feet, turn over controls and start with commentary and ratings
  3. Test Director
    a. Take notes on evaluation pilot commentary and performance
    b. Prompt evaluation pilot as necessary

L. Setup for next approach
  1. Safety Pilot
    a. Fly aircraft to initial condition
    b. Look for traffic
  2. Evaluation Pilot
    a. Continue commentary and ratings for last approach
    b. Brief next approach with Test Director
  3. Test Director
    a. Make decision on next approach - nominally continue as planned
    b. De-brief last approach with evaluation pilot
    c. Brief next approach
    d. Check weather trends
  4. Test Engineer
    a. Prepare for next approach
  5. MMW Engineer
    a. Monitor image
    b. Monitor data recording equipment

6. Weather Analyst
    a. Insure weather sensor is operational

M.. De-brief after returning to base
1. Safety Pilot
    a. Discuss any problems noted during the flight
    b. Give perceptions of performance
2. Evaluation Pilots
    a. Initial debrief of each evaluation pilot separately - ratings and commentary
    b. Discuss results with both evaluation pilots present
    c. Make any recommendations that seem appropriate
3. Test Director
    a. Go over ratings and commentary with evaluation pilots
    b. Summarize problems that need to be resolved, and assign action items to be completed before the next flight
    c. Plan for next sortie
    d. Review data tapes with Test Engineer
4. Test Engineer
    a. Advise Test Director of any problems
    b. Outline plan for reducing aircraft performance data
5. MMW sensor Engineer
    a. Advise Test Director of any problems
    b. Outline plan for reducing radar data
6. Weather analyst
    a. Advise Test Director of any problems
    b. Outline plan for reducing weather data

X. PILOT QUALIFICATIONS AND TRAINING

A. Pilot Qualifications

The safety pilots are experienced Gulfstream II captains and have ATP ratings. They are employed by Raleigh Jet. The evaluation pilots are all qualified test pilots. Two are employed by Douglas Aircraft, one is an FAA employee, and one is an Air Force test pilot. Of these four, three will be selected as the primary evaluators, and one will be a backup.

B. Pilot Training

All of the evaluation pilots will go through a week of training on the G-II aircraft at Simuflight in Dallas Texas. Upon completion of this training they will meet the standards for second in command on the G-II as established by Raleigh Jet. The simulator is a Phase II device, and therefore extensive training in the aircraft is not felt to be required. The baselining flights will provide G-II flight experience in VMC conditions, while simultaneously obtaining data for the project. The training at Simuflight will include crew coordination specifically oriented towards the G-II in the context of the SVS procedures. The Test Director will participate in this part of the training at Simuflight. Additional pilot training, and development of crew procedures will be accomplished in a simulation being conducted at Douglas Aircraft. This element of the program includes a fixed base simulator (MD-11 cockpit and aero model),

the GEC HUD and symbology to be used in the G-II, a simulation of MMW and FLIR superimposed on the HUD symbology, and a camera-model visual system. The evaluation pilots for the flight program will all participate in the simulation tests. This will provide considerable training in the use of the HUD and its symbology, as well as the SVS procedures.

During demonstration flights, the evaluation seat (right seat) will be occupied by a non-trained individual. Therefore, a Raleigh Jet pilot will occupy the jump seat for those flights.

DEPARTMENT OF TRANSPORTATION

FEDERAL AVIATION ADMINISTRATION

CERTIFICATE OF WAIVER OR AUTHORIZATION

ISSUED TO

Peterson Aviation

ADDRESS

7155 Valjean Avenue, Van Nuys, CA 91406-3917

This certificate is issued for the operations specifically described hereinafter. No person shall conduct any operation pursuant to the authority of this certificate except in accordance with the standard and special provisions contained in this certificate, and such other requirements of the Federal Aviation Regulations not specifically waived by this certificate.

OPERATIONS AUTHORIZED

This certificate is issued to satisfy the test plan requirement of the Synthetic Vision Technology Demonstration Project. The certificate holder is authorized to conduct straight-in approach and landing operations to Category IIIa (RVR 700, DH 50') landing minimums using their Gulfstream, G1159, S/N005, N65ST equipped with and operating head-up guidance display (HUD) and millimeter wave/FLIR imagery in accordance with the special provisions of this certificate.

LIST OF WAIVED REGULATIONS BY SECTION AND TITLE

Federal Aviation Regulation Part 91.175(c), (d), and (g), Takeoff and Landing Under IFR; (c) Operation below DH or MDA, (d) Landing, (g) Military Airports.

STANDARD PROVISIONS

1. A copy of the application made for this certificate shall be attached to and become a part hereof.
2. This certificate shall be presented for inspection upon the request of any authorized representative of the Administrator of the Federal Aviation Administration, or of any State or municipal official charged with the duty of enforcing local laws or regulations.
3. The holder of this certificate shall be responsible for the strict observance of the terms and provisions contained herein.
4. This certificate is nontransferable.

NOTE—This certificate constitutes a waiver of those Federal rules or regulations specifically referred to above. It does not constitute a waiver of any State law or local ordinance

SPECIAL PROVISIONS

Special Provisions Nos. 1 to 12, inclusive, are set forth on the reverse side hereof.

This certificate is effective from August 19, 1992 to May 30, 1993, inclusive, and is subject to cancellation at any time upon notice by the Administrator or his authorized representative.

BY DIRECTION OF THE ADMINISTRATOR

Washington, D.C.
(Region)

(Signature)

August 19, 1992
(Date)

Manager, All Weather Operations Branch
(Title)

FAA Form 7711-1 (7-74)

SPECIAL PROVISIONS

1. With the exception of Section 91.175(c)(d) and (g) of the Federal Aviation Regulations (FAR), all applicable FAR must be complied with including Section 91.319 of the FAR.

2. This certificate of waiver does not grant relief from any limitations as set forth on the Experimental Category (CAT) Airworthiness Certificate.

3. During flight operations in weather conditions below CAT I instrument landing system (ILS) minimums for the approach being conducted and when the aircraft is maneuvered by reference to synthetic vision/head-up display (SV/HUD) technology, the aircraft shall be operated by a three-person cockpit crew, a pilot-in-command (PIC) who shall act as safety pilot, a second-in-command (SIC) who shall act as evaluation pilot, and a test director who shall be stationed in the forward observer seat. Any individual functioning as PIC shall possess an airline transport pilot airman certificate with a G-1159 type rating, a current PIC proficiency check in G-1159 aircraft in accordance with Section 61.58 of the FAR, and recency of experience in the G-1159 aircraft in accordance with Section 61.57 of the FAR. Any individual functioning as SIC shall possess a current SIC proficiency in G-1159 aircraft in accordance with Section 61.55 of the FAR. All three cockpit crewmembers shall become familiar with the SV/HUD equipment being used by utilizing all available training resources. Cockpit duties shall be shared by all three crewmen as appropriate, and good cockpit resource management practices shall be used at all times. The test director stationed in the forward observer seat shall be either Mr. Roger Hoh, or any of the three Peterson Aviation personnel designated and trained to serve as PIC on this aircraft. Interested individuals who are not subject pilots and who wish to observe the operation of the SV/HUD equipment are prohibited from occupying the PIC, SIC, or forward observers seat when conducting flight operations in weather conditions below CAT I ILS minimums for the approach being conducted and when the aircraft is maneuvered by reference to SV/HUD technology. error

4. Flight operations in weather conditions below CAT I ILS minimums for the approach being conducted, and when the aircraft is maneuvered by reference to SV/HUD technology are limited to the following facilities:

a. Arcata-Eureka, CA (ACV); ILS RWY 32
b. Santa Maria Public, CA (SMX); ILS RWY 12
c. Vandenberg AFB (VBG); ILS RWY 12 and ILS RWY 30
d. Santa Barbara Municipal, CA (SBA); ILS RWY 7
e. Point Mugu NAWS (NTD); ILS RWY 21

Formal coordination will be accomplished with the appropriate air traffic control (ATC) facilities prior to initiating the proposed study and conducting flight operations in weather conditions below CAT I ILS minimums for the approach being conducted when the aircraft is maneuvered by reference to SV/HUD technology. As a minimum, ILS critical areas must be discussed with the appropriate ATC facilities, and a copy of this waiver with special provisions attached will be provided.

5. Prior to initiating the proposed study, a minimum of five ILS approaches must be executed at each of the approved facilities to be used. These five approaches will be conducted from the final approach fix through straight-in landing, roll out, and full stop using the SV/HUD equipment to be used during the study, and will be conducted when weather conditions are at or above published CAT I ILS minimums for the published approach. Any anomalies detected in the ground- or aircraft-based equipment will be noted. Detailed information on the performance of the ground- or aircraft-based equipment will be recorded on each of the five approaches conducted at each facility. Any anomaly noted in the performance of ground-based equipment that results in an unsatisfactory flare angle, landing, and/or rollout performance, and/or that results in the unsatisfactory execution of a go-around will disqualify that ILS facility from this study, and relief from Section 91.175(c) (d) and (g) for that facility is rescinded.

6. In addition to the five approaches required in paragraph 5 above, a minimum of two approaches must be executed at each of the approved facilities to be used, and must include a representative from the Federal Aviation Administration (FAA) acceptable to the FAA's Technical Programs Division, AFS-400 as a member of the cockpit crew. These two approaches may be conducted concurrently with the five approaches required in paragraph 5 above, and, if so, an appropriate number of high-speed simulated roll-out tests will be conducted to meet the requirements of paragraph 5. These approaches will be conducted when weather conditions are at or above visual flight rules (VFR) minimums, and will be conducted from the final approach fix to a point not sooner than 50 feet above the landing runway threshold at which time the published missed-approach procedure will be initiated and not later than aircraft touchdown. These approaches will be conducted in order to assess the obstacle environment during the missed-approach procedure and will take into account guidance from FAA Advisory Circular 120-29, Criteria for Approving Category I and Category II Landing Minima for FAR 121 Operators, appendix 2, paragraphs 4, 6, 7, and 8, and FAA Order 6750.24b, ILS and Ancillary Electronic Component Configuration and Performance Requirement. Based on his/her evaluation, any of the approved facilities to be used during the study may be disqualified and relief from FAR Section 91.175(c) (d) and (g) for that facility will be rescinded. If an alternate

missed-approach procedure can be obtained from the appropriate air traffic control facility in a letter of agreement, and it is evaluated by the same FAA representative, the approach facility may re-qualify for the study. In this case, all missed-approaches must utilize the alternate procedure.

7. During the conduct of the study, while performing flight operations in weather conditions below CAT I ILS minimums for the approach being conducted, and when the aircraft is maneuvered by reference to SV/HUD technology, the touchdown zone RVR reporting system, if available, must be used. The touchdown zone RVR report is controlling for these operations, and the rollout and/or mid RVR report provides advisory information only. The lowest weather conditions authorized to proceed with an approach past the final approach fix to the final approach segment and continue to straight-in landing and roll-out is RVR 700. If RVR reporting is not available, a prevailing visibility of 1/8 mile is required.

8. During the conduct of the study, while performing flight operations in weather conditions below CAT I ILS minimums for the approach being conducted, and when the aircraft is maneuvered by reference to SV/HUD technology, a decision height (DH) of 200 feet above the runway threshold elevation determined by the barometric altimeter and an alert height (AH) of 0 feet (aircraft touchdown) shall be utilized as follows. Before descending to a DH of 200 feet, the PIC, with input from the other two cockpit crewmembers as appropriate, shall determine that all aircraft and/or SV/HUD systems are functioning normally, and that the aircraft is in a stabilized, approach profile in the landing configuration, on course and glideslope, and at the appropriate approach reference speed. When all the above conditions are confirmed, and the evaluation pilot has announced "RUNWAY IMAGE," descent below 200 feet is authorized and a decision to land will be announced by the PIC. At any time from DH 200 to AH 0 that any cockpit crewmember becomes aware of any malfunction of the aircraft and/or SV/HUD systems, or if the aircraft deviates from a stabilized, approach profile, and/or from an on-course and on glideslope indication, and/or from the appropriate approach reference speed, that person shall announce "GO-AROUND" and the evaluation pilot shall initiate the appropriate missed-approach procedure. For the purposes of this paragraph, the aircraft will be considered in a stabilized, approach profile when:

a. The airplane is in trim so as to allow for continuation of normal approach and landing.

b. The indicated airspeed and heading are satisfactory for a normal flare and landing. Airspeed must be at the appropriate approach reference speed, +5 -0 knots.

c. The airplane is positioned so that the cockpit is within and tracking so as to remain within the lateral confines of the extended runway.

d. Deviation from glideslope does not exceed ± 75 microamps as displayed on the ILS indicator.

e. No unusual roughness or excessive attitude changes occur after leaving the middle marker.

9. Flight operations in weather conditions below CAT I ILS minimums for the approach being conducted when the aircraft is maneuvered by reference to SV/HUD technology are not authorized when the crosswind component for the landing runway is greater than 10 knots.

10. Runway field length requirements for flight operations in weather conditions below CAT I ILS minimums for the approach being conducted when the aircraft is maneuvered by reference to SV/HUD technology will be increased 25 percent over field length requirements published in the aircraft flight manual (AFM) to execute a full stop landing on a dry or damp runway. If runway conditions are wet and/or if the 25 percent increase requirement cannot be met, the appropriate AFM requirements must be met, and flight operations are limited to weather conditions at or above CAT I ILS minimums for the approach being conducted. Touch-and-go operations may be conducted using field length requirements published in the AFM.

11. Flight operations in weather conditions below CAT I ILS minimums for the approach being conducted when the aircraft is maneuvered by reference to SV/HUD technology are not authorized if any component of the CAT I ILS system is inoperative.

12. During the conduct of this study a "building block" method will be used to advance from CAT I ILS minimums to lowering weather minima. A minimum of three successful approaches will be conducted before proceeding to the next lower minima. The minima will be reduced as follows:

a. From CAT I ILS to RVR 1,200
b. From RVR 1,200 to RVR 700

cc:
AFS-400 (AFS400-92-0435 sus: 8/31/92)
AFS-410
ATP-120
AWP-FSDO-01
AWP-200
ANM-160L Chip Adam
AFS410:Robinson:cjs:77211:8/19/92 (wp51\aug\special.pro)
FILE: 8405-08-15

APPENDIX G

LIST OF AVAILABLE RAW DATA FROM HONEYWELL 35 GHz RADAR

APPENDIX G

LIST OF AVAILABLE RAW DATA FROM 35 GHZ RADAR

The raw radar data list presented as Table A-1 is a complete listing of all radar data approaches for which data were received and processed by GTRI. Specific raw-data "snapshot" files included in this table have 10-digit names. The format of these names, from left to right, is: a three-digit Julian day, a two-digit hour, a two-digit minute, a decimal point, and finally, a two-digit second. All times are expressed as Greenwich mean times. Unless otherwise specified, all snapshots are selected so as to coincide as closely as possible with the appropriate altitudes or ranges. In all cases, altitudes are expressed in feet. The use of "n/a" denotes data unavailable due primarily to incomplete approaches, and any empty blocks represent data that were available but were not processed.

The "Date" is presented in month-day-year format. The notes included within the date column are defined in the legend at the end of the list. These notes help to explain some of the apparent inconsistencies found within the radar data altitude information. The "Sortie/Approach" is the sortie number and approach letter for the specific entry. The use of "T" in the "Sortie/Approach" column represents a take-off. The "Airport" column presents the official three-letter airport designation for that entry. The "Weather" is presented as either clear, fog rain, or snow, and sometimes with the following additional designations for some clear weather approaches: special (spc), runway intrusion (rwi), and calibration (cal).

The remaining columns present the specific radar data snapshots processed for purposes of calculating contrast, sharpness, and variability parameters. The snapshots are designated according to their IRIG time codes and all altitudes correspond to the blended altitude reported in the radar data header. The 50 feet altitude image represents the nominal flare point, and the 200 feet altitude image represents the Category I decision height. The 2500 meter range image is based on the altitude that corresponds with the 2500 meter slant range and the specific airport glide slope (e.g. 429 feet at 3.0 degree glide slope). The pilot detection image is based on the pilot runway call-out altitude and the corresponding range to threshold. The deviation column represents the difference in feet between the pilot's runway call-out range to threshold and the range to threshold for the nearest available raw-data snapshot.

TABLE A-1. Complete GTRI Raw Radar Data List For Honeywell 35 GHz Sensor

	Sortie			50' Altitude Image		200' Altitude Image		2500m Range Image		Pilot Detection Image		
Date	Approach	Airport	Weather	time code	altitude	time code	altitude	time code	altitude	time code	altitude	dev. (ft)
080492	1A	NTD	clear	2172142.30	63.02	2172142.18	231.22	2172142.02	408.57	2172142.14	286.97	114
	1B	NTD	clear	n/a	n/a	n/a	n/a	n/a	n/a	2172157.22	553.94	174
080892	1A	VBG	fog	n/a	n/a	2211437.48	201.54	2211437.36	394.43			
	1B	VBG	fog	n/a	n/a	2211449.28	201.49	2211449.12	442.35	n/a	n/a	n/a
	1C	VBG	fog	n/a	n/a	2211501.16	191.88	2211501.00	411.86			
	1D	VBG	fog	n/a	n/a	2211512.12	195.54	2211511.56	420.69	n/a	n/a	
	1E	VBG	fog	n/a	n/a	2211523.32	197.84	2211523.16	460.41			
	1F	VBG	fog	n/a	n/a	2211534.44	185.23	2211534.28	397.18	n/a	n/a	
	1G	VBG	fog	2211546.28	38.45	2211546.08	214.56	2211545.56	416.15			
081192												
[R2]	1A	VBG	fog	n/a	n/a	2241433.00	207.81	2241432.48	375.53	2241432.43	430.45	201
	1B	VBG	fog	2241445.24	62.17	2241445.08	214.92	2241444.52	440.42	n/a	n/a	n/a
[S1]	1C	VBG	fog	2241458.52	41.14	2241458.28	220.18	2241458.16	418.59	2241458.16	418.59	319
[S2]	1D	VBG	fog	n/a	n/a	n/a	n/a	2241510.52	395.06	n/a	n/a	n/a
	1E	VBG	fog	n/a	n/a	2241526.16	227.50	2241526.00	448.30	2241525.56	498.42	370
	1F	VBG	fog	2241536.56	61.52	2241536.44	211.47	2241536.28	430.26	n/a	n/a	n/a
081192												
[R2][S3]	2A	VBG	fog	2241858.11	37.05	2241857.55	221.15	2241857.43	397.52	n/a	n/a	n/a
	2B	VBG	fog	2241912.39	59.65	2241912.23	226.50	n/a	n/a	n/a	n/a	n/a
081392	1A	VBG	fog	n/a	n/a	2261427.32	230.99	2261427.20	397.45			
	1B	VBG	fog	n/a	n/a	2261439.04	223.45	2261438.47	443.82	n/a	n/a	n/a
	1C	VBG	fog	n/a	n/a	2261450.28	228.31	2261450.08	452.46			
	1D	VBG	fog	n/a	n/a	n/a	n/a	2261503.36	435.54	n/a	n/a	n/a
	1E	VBG	fog	n/a	n/a	2261515.16	226.18	2261515.00	434.27			
	1F	VBG	fog	n/a	n/a	2261525.56	233.11	2261525.40	403.51	n/a	n/a	n/a
	1G	VNY	clear	2261553.16	54.21	2261553.04	224.36	2261552.44	561.57			

TABLE A-1. Complete GTRI Raw Radar Data List For Honeywell 35 GHz Sensor (continued)

	Sortie			50' Altitude Image		200' Altitude Image		2500m Range Image		Pilot Detection Image		
Date	Approach	Airport	Weather	time code	altitude	time code	altitude	time code	altitude	time code	altitude	dev.(ft)
081392	2A	NTD	clear	n/a	n/a	n/a	n/a	n/a	n/a			
	2B	NTD	clear	2262038.49	44.37	2262038.37	180.81	2262038.17	427.60			
	2CT	NTD	clear	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
	2C	NTD	clear	2262100.13	66.31	2262100.01	184.76	2262059.37	449.03			
	2DT	NTD	clear	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
	2D	NTD	clear	2262119.17	43.81	2262119.01	204.29	2262118.36	458.95			
081392	3A	NTD	clear	2262234.34	56.49	2262234.26	199.80	2262234.14	417.79			
	3B	NTD	clear	2262246.38	36.56	2262246.30	163.68	2262246.18	417.72			
	3C	NTD	clear	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
081892	1A	LAX	clear/spc	2311427.13	28.32	2311427.01	190.32	2311426.45	414.99			
	1B	LAX	clear/spc	n/a	n/a	2311442.21	227.52	2311442.05	446.32			
	1C	LAX	clear/spc	2311457.41	30.04	2311457.29	207.34	2311457.09	441.23			
	1D	SAN	clear/spc	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
	1E	SAN	clear/spc	2311601.05	43.65	2311600.45	205.20	2311600.33	400.10			
	1F	SAN	clear/spc	2311613.05	42.82	2311612.49	199.30	2311612.37	417.97	n/a	n/a	n/a
	1G	CRQ	clear/spc	2311628.09	48.49	2311627.49	205.94	2311627.25	463.44			
	1H	CRQ	clear/spc	2311641.17	56.49	2311641.01	197.91	2311640.37	463.23			
	1I	CRQ	clear/spc	2311652.53	64.79	2311652.33	216.15	2311652.09	472.93			
081892	2A	NTD	clear/rwi	n/a	n/a	2320017.06	179.54	2320016.46	444.49			
	2B	NTD	clear/rwi	2320031.50	37.29	2320031.38	200.21	2320031.22	444.64			
	2C	NTD	clear/rwi	n/a	n/a	2320046.30	223.37	2320046.14	419.18			
	2D	NTD	clear/rwi	2320059.06	40.38	2320058.53	209.43	2320058.34	453.30	n/a	n/a	n/a
	2E	NTD	clear/rwi	n/a	n/a	n/a	n/a	2320111.06	424.60			
	2F	NTD	clear/rwi	2320123.30	51.80	2320123.18	208.94	2320123.02	424.14			

TABLE A-1. Complete GTRI Raw Radar Data List For Honeywell 35 GHz Sensor (continued)

	Sortie			50' Altitude Image		200' Altitude Image		2500m Range Image		Pilot Detection Image		
Date	Approach	Airport	Weather	time code	altitude	time code	altitude	time code	altitude	time code	altitude	dev.(ft)
081992	1A	SBA	clear/cal	2321849.11	30.72	2321848.55	221.22	2321848.39	431.91	2321848.39	431.91	6
	1B	SBA	clear/cal	2322025.36	28.17	2322025.20	217.17	2322025.04	442.00	n/a	n/a	n/a
	1C	SBA	clear/cal	2322037.00	58.77	2322036.48	208.29	2322036.32	437.66	2322036.36	371.50	156
	1D	SBA	clear/cal	2322048.00	26.29	2322047.44	224.20	2322047.28	454.65	2322047.40	282.59	151
081992	2A	VBG	clear	n/a	n/a	2322127.52	212.16	2322127.40	401.86	n/a	n/a	n/a
	2B	VBG	clear	2322132.08	46.34	2322131.56	182.75	2322131.43	413.98	n/a	n/a	n/a
	2C	VBG	clear/cal	2322239.58	48.74	2322239.46	183.36	2322239.30	426.52	n/a	n/a	n/a
	2D	VBG	clear/cal	2322304.50	48.25	2322304.34	211.22	2322304.18	438.07	n/a	n/a	n/a
082092	1A	SMX	clear/cal	2331734.42	47.98	2331734.30	223.59	2331734.14	443.92	2331734.18	381.10	181
	1B	SMX	clear/cal	2331857.34	43.47	2331857.22	230.28	2331857.10	411.80	2331857.14	356.24	397
	1C	SMX	clear/cal	2331907.46	51.62	2331907.38	189.75	2331907.22	437.61	2331907.26	384.73	287
082792												
[S1]	1B	VBG	fog	2401500.45	56.06	2401500.33	186.60	2401500.21	389.60	2401500.09	572.51	118
[S1]	1C	VBG	fog	2401513.41	39.49	2401513.21	216.27	2401513.05	460.69	2401513.05	460.69	167
	1D	VBG	fog	2401524.32	36.93	2401524.13	224.73	2401524.01	407.31	2401524.09	287.50	417
[R1]	1E	VBG	fog	2401535.21	45.49	2401535.09	162.95	2401534.49	426.60	2401534.44	489.66	2607
[S1]	1F	VBG	fog	2401546.32	n/a	2401546.25	176.97	2401546.09	397.27	2401545.49	659.56	385
[R2]	1G	VBG	fog	n/a	n/a	n/a	n/a	2401556.57	411.97			
082792	2A	ACV	clear/cal	2402205.57	25.08	2402205.48	160.84	2402205.28	451.61	2402205.05	701.22	572
	2B	ACV	clear/cal	2402228.25	65.57	2402228.17	200.12	2402228.01	414.96	2402227.52	505.87	2993
	2C	ACV	clear/cal	2402305.21	62.70	2402305.13	215.06	2402304.53	434.41	2402304.41	587.17	299

TABLE A-1. Complete GTRI Raw Radar Data List For Honeywell 35 GHz Sensor (continued)

	Sortie			50' Altitude Image		200' Altitude Image		2500m Range Image		Pilot Detection Image		
Date	Approach	Airport	Weather	time code	altitude	time code	altitude	time code	altitude	time code	altitude	dev.(ft)
082892	1A	ACV	fog	2411520.34	38.11	2411520.22	215.89	2411520.06	416.79	2411520.10	393.28	35
	1B	ACV	fog	2411536.58	39.46	2411536.46	223.99	2411536.29	433.12	2411536.29	433.11	103
[R1][R2]	1C	ACV	fog	n/a	n/a	2411548.18	222.56	2411548.06	400.02	2411548.06	400.02	139
	1D	ACV	fog	2411600.10	59.66	2411600.02	210.08	2411559.41	401.85	2411559.38	465.85	165
	1E	ACV	fog	2411617.25	50.34	2411617.18	216.63	2411616.58	434.10	2411616.50	538.76	1309
	1F	ACV	fog	2411628.58	40.79	2411628.46	187.50	2411628.29	420.17	2411628.25	449.85	3874
	1G	ACV	fog	2411640.38	69.15	2411640.29	227.85	n/a	n/a	2411640.25	294.45	7548
	1H	ACV	fog	2411653.14	30.18	2411653.02	220.64	2411652.45	415.35	2411652.41	464.66	2175
082892	2A	ACV	fog	n/a	n/a	2411817.08	175.64	2411816.44	437.02	2411816.32	591.09	222
	2B	ACV	fog	2411828.52	35.39	2411828.44	171.57	2411828.24	418.13	2411828.12	587.28	423
092692	1A	WRI	rain	n/a	n/a	2701501.52	207.42	2701501.00	447.85	n/a	n/a	n/a
092792	1A	ACY	clear	2711755.30	32.96	2711755.18	193.52	2711755.02	426.14	n/a	n/a	n/a
	1B	MIV	clear	2711814.26	53.10	2711814.14	210.28	2711813.58	413.54	n/a	n/a	n/a
	1C	NHK	clear	2711847.26	60.12	2711847.18	191.13	2711846.58	451.82	n/a	n/a	n/a
092892	1A	HTS	fog	n/a	n/a	n/a	n/a	2721137.30	414.12	2721137.18	565.28	280
[R1]	1B	HTS	fog	2721147.10	49.76	2721147.02	254.34	2721146.50	438.70	2721146.42	568.26	187
[S4][R2]	1D	HTS	fog	n/a	n/a	2721203.46	194.11	2721203.22	487.28	2721203.22	487.28	161
[S5]	1E	HTS	fog	n/a	n/a	2721214.01	240.69	2721213.46	468.71	2721213.37	563.52	387
112092	1B	PUB	snow	3260202.06	39.24	3260201.50	208.90	3260201.34	414.54	n/a	n/a	n/a
	1C	PUB	snow	3260213.50	59.90	3260213.38	204.40	3260213.22	420.98	n/a	n/a	n/a
	1D	PUB	snow	3260225.22	39.30	3260225.10	178.52	3260224.50	424.41	n/a	n/a	n/a
	1E	PUB	snow	3260236.30	19.90	3260236.14	205.66	3260235.54	446.33	n/a	n/a	n/a

TABLE A-1. Complete GTRI Raw Radar Data List For Honeywell 35 GHz Sensor (continued)

	Sortie			50' Altitude Image		200' Altitude Image		2500m Range Image		Pilot Detection Image		
Date	Approach	Airport	Weather	time code	altitude	time code	altitude	time code	altitude	time code	altitude	dev.(ft)
112192	1A	PUB	snow	3261758.48	57.12	3261758.36	209.24	3261758.20	441.73	3261758.36	209.24	219
	1B	PUB	snow	3261810.12	30.81	3261809.56	215.53	3261809.40	434.51	3261810.00	162.56	64
	1C	COS	snow	3261823.16	45.10	3261823.04	186.08	3261822.48	409.25	3261822.56	307.27	336
	1D	COS	snow	3261835.44	28.53	3261835.32	200.32	3261835.16	449.85	n/a	n/a	n/a
112792	1A	NTD	clear/cal	3322252.02	58.30	3322251.54	213.40	3322251.46	436.97	n/a	n/a	n/a
	1B	NTD	clear/cal	3330007.15	40.65	3330007.07	196.43	3330006.59	406.95	n/a	n/a	n/a
	1C	NTD	clear/cal	3330017.03	53.95	3330016.55	188.97	3330016.43	483.69	n/a	n/a	n/a
	1D	NTD	clear/cal	3330026.03	56.08	3330025.51	209.86	3330025.39	415.87	n/a	n/a	n/a
	1E	NTD	clear/cal	3330035.03	62.00	3330034.55	188.89	3330034.39	462.98	n/a	n/a	n/a
	1F	NTD	clear/cal	3330045.15	68.41	3330045.07	169.35	3330044.55	396.16	n/a	n/a	n/a
	1G	VNY	clear	3330100.55	32.21	3330100.42	245.70	3330100.27	598.81	n/a	n/a	n/a

LEGEND

[R1] = Altitude for 200' altitude snapshot is suspect. Replaced with next closest snapshot.
[R2] = Altitude for 2500m range snapshot is suspect. Replaced with next closest snapshot.
[S1] = Blended altitude suspect. Appears 50' too high for the 2500m range snapshot.
[S2] = Blended altitude suspect. Appears 80' too high for the 2500m range snapshot.
[S3] = Blended altitude suspect. Appears 50' too high for the 2500m range snapshot. (Even after replacement)
[S4] = Blended altitude suspect. Appears 70' too high for the 200' altitude snapshot.
[S5] = Blended altitude suspect. Appears 80' too high for the 200' altitude snapshot.

APPENDIX H.

COMPUTATION OF WEATHER-RELATED METRICS

APPENDIX H
COMPUTATION OF WEATHER-RELATED METRICS

H.1 EXAMINATIONS OF JTD-DERIVED QUANTITIES

H.1.1 CALCULATION OF VISUAL RANGE

Visual range was calculated by JTD during the conversion of the archive data into the profiles of average and integrated values. The formula used by JTD is a common expression for the estimation of visual range based on several assumptions. The first assumption made is that the particle sizes are sufficiently large, compared with the wavelength of the incident radiation, that one can consider the backscatter coefficient of the particles to be twice the projected surface area of the drop on a plane. A second assumption made is that there is no shadowing of one drop by another. The basic formula used in this calculation is shown in Equation H-1 below:

$$V = \frac{\ln (1/0.02)}{\sum_{i=1}^{b} N_i (2SA_i)}, \tag{H-1}$$

where N_i are the number concentrations in each size bin, SA_i is the average projected surface area of the particles counted in the ith bin, b is the number of bins, and V is the visibility.

This formula can be derived from the basic equation relating transmissivity, T, with the transmittance, t_L, over a given path on length, L.[1] Transmittance, t_L, is defined as the ratio of the transmitted radiant flux, Φ_0, to the incident radiant flux, Φ_i.

$$t_L = \Phi_0 / \Phi_i \tag{H-2}$$

This quantity can be also be defined using the optical extinction coefficient as

$$t_L = e^{-\alpha L}, \tag{H-3}$$

1 C. A. Douglas and R. L. Booker, *Visual Range: Concepts, Instrumental Determination, and Aviation Applications*, NBS Monograph 159, National Bureau of Standards, 1977.

where α is the extinction coefficient. Transmissivity is defined as the transmittance per unit length in the transmission medium, and can be related to the transmissivity through the relationship,

$$T = t_L^{1/L} \tag{H-4}$$

The visual range, V, can then be related to the transmissivity and a defined contrast threshold, ε, using the following relation.

$$\varepsilon = T^{V} \tag{H-5}$$

If one takes the logarithm of both sides of Equation H-5, substitutes the expression relating t_L to T found in Equation H-4, and then uses the identity defined in Equation H-3, one obtains the following simple relationship between V and the extinction coefficient for a single uniform layer.

$$V = -\ln(\varepsilon) / \alpha = \ln(1 / \varepsilon) / \alpha \tag{H-6}$$

This is the basic expression used by JTD in calculating the slant visual from the drop size distributions. In their calculations, JTD used a contrast threshold of 0.02, rather than the FAA operational value of 0.05. This results in an overestimation of the visual range with respect to the FAA value by a factor of 1.306 on the JTD graphs.

The extinction coefficient, α, can be derived as

$$\alpha = \sum_{i=1}^{b} Q_i N_i (\pi/4) D_i^2, \tag{H-7}$$

where Q_i is the extinction coefficient for particles in the i^{th} size bin, N_i is the number concentration of these particles, and D_i is the mean diameter within the size bin. The summation is performed over all the size bins measured. For optical wavelengths, the extinction coefficient due to fog and rain particles is due mainly to scattering and can be simply estimated as $Q_i = 2$ for all size bins. This substitution for Q leads to the simple expression used operationally by JTD, which is

$$V = \frac{\ln\left(\frac{1}{0.02}\right)}{(\pi / 2) \sum_{i=1}^{b} \overline{N}_i D_i^2} = \frac{\ln\left(\frac{1}{0.02}\right)}{2 \sum_{i=1}^{b} \overline{N}_i SA_i} \tag{H-8}$$

In this equation, $\overline{N}_i$ represents the integrated average number concentration over the layer between the aircraft position and the ground, and SA_i is the mean surface area of the particles in each size bin. Some questions were raised as to whether this relationship was strictly valid or only an approximation to the correct expression for slant visual range. Equation H-8 is, in fact, a valid re-lationship which may be used to calculate visual range.

The transmittance over the entire path, L, can be written in terms of the individual transmittances over each of the layers of depth, d_i, as

$$\exp(-\alpha_T L) = \Pi_i \exp(-\alpha_i d_i), \tag{H-9}$$

where α_T represents the total path extinction coefficient, L represents the total path length, α_i represents the extinction coefficient within layer i, d_i represents the depth of layer i, and Π_i indicates the product of the exponentials over the range of i. If the exponentials in the product are replaced with the flux ratios defined in Equation H-2, then this yields the correct result, the ratio of the incident to the transmitted flux.

The relation between the contrast threshold, the transmissivity, and the visual range, can then be used, after the application of logarithms to both sides and the substitution of the transmittance equation for the transmissivity, to produce the following relationship between visual range V, the con-trast threshold ε, the total path length L, the extinction coefficients within each layer α_j, and the depth of each layer d_j:

$$V = \frac{(-L \ln \varepsilon)}{\sum_{j=1}^{n} -(\alpha_j d_j)} \tag{H-10}$$

where n is the total number of layers.

If one substitutes an expression for the drop size dependent extinction coefficient within each layer for α_j, the equation becomes

$$V = \frac{-L \ln \varepsilon}{\sum_{j=1}^{n} d_j \sum_{i=1}^{b} \left(-Q_i N_{ji} (\pi/4) D_i^2\right)} \qquad \text{(H-11)}$$

where the sum over i is taken over the number of size bins, and the sum over n is taken over the number of layers.

Since each of the layers in the profile data sets had the same depth, we can represent that standard layer depth by "d" and remove this factor from the sums. Since Q_i and D_i are not dependent on the specific layer, these factors also may be removed from the sum over the n layers and the expression may be rewritten as

$$V = \frac{-(4/\pi) L \ln \varepsilon}{d \sum_{i=1}^{b} \left(Q_i D_i^2 \sum_{j=1}^{n} N_{ji} \right)} \qquad \text{(H-12)}$$

The sum over the layers of the number concentrations in each size bin, $\Sigma_j N_{ji}$, is the integrated average number concentration within each size bin times the number of layers, $n\overline{N}_i$. The removal of the factor n, the cancellation of the total path length L by the factor nd, and the assumption that $Q_i = 2$, yields the following final expression for the layered visual range calculation,

$$V = \frac{-\ln \varepsilon}{(\pi/2) \sum_{i=1}^{b} \left(\overline{N}_i D_i^2\right)}, \qquad \text{(H-13)}$$

This is the same equation as was presented earlier as Equation H-8 and is the equation which was used by JTD in deriving slant path visual range.

The relation expressed in Equation H-8 was applied by GTRI to the number concentration values supplied by JTD for a number of runs as a final check of the JTD-provided graphs as well

as to provide tabular input for the sensor evaluation database. The computed values agreed with the graphical presentations provided by JTD.

H.1.2 CALCULATION OF LIQUID WATER CONTENT

Four liquid water content (LWC) values were provided for each approach in the profile data sets provided by JTD. These values were the LWC measured by the JW hot-wire sensor (JW-LWC), the LWC calculated from the drop size distribution measured by the FSSP fog droplet probe (FSSP-LWC), the LWC calculated by the alternate OAP probe (PMS2-LWC), and a combined LWC cal-culated from an appropriate combination of data from the two drop size probes (TOTAL-LWC).

These LWC values were compared in order to assess the consistency of the data set. This examination revealed potential errors in the JW-LWC values. These errors are discussed in Section H.1.2.1. The method used to compute the total LWC from the two-probe data sets was also examined by GTRI and is discussed in Section H.1.2.2.

H.1.2.1 Data Received from JW LWC Probe

The liquid water content values measured by the JW hot-wire device were compared to the total LWC values determined by combining the calculated LWC values from the two PMS probes for a number of approaches. The JW and total LWC values often differed by a factor of up to 2, with the JW-LWC generally producing the higher liquid water content values. JTD was asked to explain this apparent discrepancy between the two values. GTRI learned that the JW-LWC probe was designed for operation in level, constant-speed flight. The flight paths taken for this project were descents along a glide slope to the runway. As the JW-LWC device was judged to be sensitive to changes in aircraft speed and pitch, the data from this sensor must be viewed with some caution. GTRI therefore chose to use the total LWC values obtained from combining the data sets from the PMS probes (TOTAL-LWC) instead of the JW-LWC values. However, the JW-LWC values could still be used to provide an "order-of-magnitude" check on the operation of the PMS probes data sets.

H.1.2.2 Method of Determining 'Probes Liquid Water Content'

The TOTAL-LWC calculated from an appropriate combination of FSSP and OAP probe data was used to determine the liquid water content for use in the sensor evaluation database. The

method used by JTD to determine this quantity was therefore examined to confirm that it truly represented the liquid water content sampled.

Liquid water content can be calculated from a measured number concentration distribution using the formula

$$LWC = \sum_{i=1}^{b} N_i \, \rho \, (4/3) \, \pi \, r_i^3 \, , \tag{H-14}$$

where N_i is the number concentration of particles detected in size bin i, ρ is the density of the particles, and r_i is the mean radius of the particles. Again, the sum is taken over all the size bins. For measurements of rain and fog, the density can be assumed to be unity. The conversion of units to provide a measure of LWC in grams per cubic meter leads to the introduction of a multiplicative term of 10^{-12}, assuming that N_i is expressed in number per cubic meter and r_i is expressed in micrometers. The final, operational expression used to calculate LWC is therefore

$$LWC = (4/3) \, \pi \, 10^{12} \sum_{i=1}^{b} N_i \; r_i^3 \, . \tag{H-15}$$

When combining the data from the FSSP and the OAP sensors, the relative ranges of each instrument must be accounted for in the combination. The ranges of drop sizes measured by each sensor are listed below in Table H-1.

Table H-1. Instrumented Drop Size Ranges for JTD Probes

JTD Instrument Code Number	Instrument	Measurement Range
-	FSSP	2 to 47 μm
1	OAP-200X	10 to 310 μm
2	OAP-200Y	150 to 4650 μm
3	OAP-200N	70 to 2170 μm

When combining data from the FSSP with either the OAP-200Y or the OAP-200N, there is no overlap in measured particle sizes so the LWC values calculated for each size distribution may simply be added together. However, there is a gap in the measurement intervals covered by either such pair of these instruments. The resultant calculated LWC may therefore be slightly lower than the actual environmental LWC.

The combination of the FSSP and OAP-200X data sets requires a truncation of either the FSSP or the OAP-200X distributions to avoid the overlap in their measurement ranges. JTD chose to avoid the overlap by using the full range of the FSSP probe and truncating the data used from the OAP-200X probe. The OAP-200X measured particles with diameters ranging from 10 to 310 μm, with a individual measurement bin size of 20 μm. The particles counted for a specific size bin were considered to be all those particles whose diameters were within 10 μm of the mean size channel diameter. The first two size bins in the OAP-200X data set therefore represented particles with diameters from 10 to 30 and from 30 to 50 μm. Thus, data from these two bins were ignored by JTD, and only particles in larger size bins, with diameters from 50 to 310 μm, were added to the LWC obtained from the FSSP data set.

The use of the OAP-200X as a secondary probe permitted a "gap-free" characterization of the fog and cloud droplet regime, but did not provide good measurement of rain drops. The maximum drop size measurable with the OAP-200X probe was 310 μm. This represents a maximum measurable diameter of only 0.31 mm. Significant numbers of larger droplets are typically present in rain. Therefore, the use of this probe may well underestimate LWC, and several other derived quantities, when used in environments with significant rain.

H.1.3 CALCULATION OF R_0 AND N_T

The median volume radius, R_0, and the total number concentration, N_T, are useful parameters which may be used to quickly characterize and compare drop size distributions. JTD calculated these quantities in a relatively straightforward fashion. These values were only provided graphically to GTRI and therefore had to be recalculated for use in interpreting the weather and sensor data as well as for inclusion into the database. This recalculation was necessary since the values could not be read with sufficient accuracy from the JTD plots.

For cases in which the OAP-200X sensor was not used, the total number concentration, N_T, was calculated by simply summing the number concentrations in all the size channels in both

the FSSP and OAP sensor data sets. The use of the OAP-200X required a small modification of the procedure used to calculate N_T, to avoid the problem of the sensor overlap. The overlap was compensated for by not using the values in the lowest two size channels of the OAP-200X, a correction similar to that made for the LWC.

The calculation of the median volume radius, R_0, was more involved. Half of the total volume of the liquid water is represented by drops having radii less than R_0 and half of the volume is contained in drops having radii larger than R_0. Knowing the total volume taken up by all the measured drops was useful, and this parameter was computed via a side calculation while summing for N_T. In this side calculation, an array was created containing the volume for all drops counted within and below each size bin. Again, the lowest two size bins in the OAP-200X data sets were not used.

The total volume of all drops counted in all bins was then the value of this array for the largest drop size. This result can be expressed as

$$V_T = (\pi/6) \sum_{i=1}^{b} \left[N_i \, (i \, d_{inc})^3 \right], \qquad \text{(H-16)}$$

where

V_T is the total volume,
i is the bin number,
b is the total number of size bins,
N_i is the number concentration of drops in the i^{th} bin, and
d_{inc} is the diameter increment from bin to bin for the sensor in use.

Half of the total volume was considered the "median volume." Expressed algebraically, this value is

$$V_\Omega = V_T / 2 \qquad \text{(H-17)}$$

where

V_Ω is the median volume, and

V_T is the total volume.

Then, starting at the smallest size bin, one determined the bin at which the volume sum first exceeded this median volume. That is, the following sum was carried out until the value of V_n exceeded V_Ω.

$$V_n = (\pi/6) \sum_{i=1}^{b} N_i \, d_i^{\,3} \qquad \text{(H-18)}$$

where

V_n is the volume sum for drops in bins up to and including bin "n",

N_i is the number concentration of drops in the i^{th} bin,

b is the total number of size bins, and

d_i is the mean diameter of drops measured in bin "i".

The median volume radius, R_0, then lies between this bin, which will be indicated by the index i_m, and the next smaller bin, with index i_{m-1}. To determine where, within this interval, the true value of R_0 lies, the following ratio was employed,

$$\text{ratio} = \frac{V_\Omega - V(i_{m-1})}{V(i_m) - V(i_{m-1})}. \qquad \text{(H-19)}$$

This is the ratio of the difference between the median volume and the lower volume sum, to the difference between the upper and lower volume sums. This ratio is taken to be the same as the ratio of the difference between the median volume radius and the i_{m-1} bin radius, to the difference between the i_m bin radius and the i_{m-1} bin radius. The median volume radius is then expressed as

$$R_0 = R_{m-1} + \text{ratio}\,(R_m - R_{m-1}). \qquad \text{(H-20)}$$

There are assumptions inherent in this calculation. First, one assumes that volume sums are sufficiently linear to allow the ratio of these sums to be interpolated to determine the intermediate value for the mean volume radius. The second assumption in this calculation is that the radii used represent the true mean radii of the drops detected in that size bin. The difference between the mean radii used by JTD and those recommended by the equipment manufacturer were always less than one-half the size resolution of the probe. Thus, both of these errors should not compound to produce an error larger than one size channel in the determination of the median volume radius.

H.1.4 CALCULATION OF RAINFALL RATE, RR

The method used by JTD to calculate rain rate from the PMS particle probe data was investigated, verified, and used to produce independent calculations of rain rate. The calculation of rain rate uses the number concentrations derived from the raw populations within each size bin.

The number concentrations within each size channel are then assigned a terminal velocity and a volume dependent on the mean size of particles detected within the channel. Calculation of the rain rate expected from this drop size distribution is then relatively straightforward. The details of these calculations are presented below.

The rain rate expected from the drops counted in size bin "j" is calculated as

$$RR_j = (4\pi/3)(r_j)^3 v_j N(D_j), \qquad \text{(H-21)}$$

where

RR_j is the rain rate,
r_j is the mean radius of drops in bin "j",
v_j is the terminal velocity for these drops, and
$N(D_j)$ is the number concentration of drops.

f the terminal velocity is given in units of meters per second; and the diameter (D_j), given in millimeters, is used in place of radius; and the number concentration is given in number per cubic meter; the equation is slightly altered and multiplied by a conversion factor. The result is

$$RR_j\,[\text{mm/hr}] = 6.0 * 10^{-4} (D_j)^3 v_j N(D_j). \qquad \text{(H-22)}$$

The total rain rate, due to particles counted in all size bins, is then simply the sum over all bins of this quantity,

$$RR_{total} = \sum_{j=1}^{n} 6.0 * 10^{-4} (D_j)^3 v_j N(D_j). \qquad \text{(H-23)}$$

The main equation used by JTD to determine terminal velocity is an empirical fit to experimental data provided by Sauvageot, [2], and has the form

$$v(D) = 965 - 1030 \exp(-6D), \qquad \text{(H-24)}$$

where

D is the particle diameter in μm,and
v(D) is the terminal velocity in cm s^{-1}.

This equation has been shown to fit the measured terminal velocities of particles whose diameters are larger than about 300 μm. For smaller particles, that is, particles from size channels with mean diameters less than 300 microns, JTD used the formula,

2 H. Sauvageot, *Radar Meteorology*, Artech House, Boston, 1992.

$$v(D) = -7.5 + 0.375\ D, \tag{H-25}$$

were the terminal velocity, v(D), is expressed in cm sec^{-1} and the drop diameter, D, is expressed in μm. This formula was based on a linear interpolation of the curve produced by the formula used for large particles (H-24) when extended towards a value of zero velocity for particles of zero diameter.

A more exact method of determining the terminal velocity at small diameters has been outlined by Beard and Pruppacher [3]. In this method, the density of the spherical droplets, ρ_s; as well as the atmospheric variables ρ_m, the density of the surrounding atmosphere, and η, the dynamic viscosity; are used to calculate the quantity $C_D R^2$. Here, C_D is the drag coefficient and R is the Reynolds number. The corresponding formula is

$$C_D R^2 = (32/3) a^3 (\rho_s - \rho_m)(\rho_m\, g / \eta^2), \tag{H-26}$$

where a is the droplet radius and g is the gravitational acceleration.

A tabulated set of values relating $C_D R^2$ to R, such as Table 1 of the Beard and Pruppacher paper, can be used to determine the Reynolds number, R, by interpolation. This value is then used in

$$V_x = R\eta / (2\rho_m a) \tag{H-27}$$

t

o determine a value for the terminal velocity, V_x.

One can then calculate some representative values of V_x at temperatures and pressures representative of those found during the flight test measurements to determine the accuracy of the JTD approximation. For this exercise, the air was assumed to be saturated at a temperature of 10° C and a pressure of 750 mm Hg. For these assumptions, the density of moist air is 1.225 kg m^{-3},

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3 K. V. Beard and H. R. Pruppacher, "A Determination of the Terminal Velocity and Drag of Small Water Drops by Means of a Wind Tunnel," *J. Atmos. Sci.*, Vol. 26, 1969, pp. 1066-1072.

or $1.225*10^{-3}$ g cm^{-3}.[4] The density of pure water at 10° C is 0.99973 g cm^{-2}. The tabulated value for the viscosity of air at 10° C is $0.177*10^{-4}$ g cm^{-1} s^{-1}. [5]

Calculations were performed over the range of 0 to 500 microns in order to compare the JTD approximation with the more exact treatment of Beard and Pruppacher. A graph comparing these results is reproduced below as Figure H-1.

Based on this figure, the JTD linear interpolation is found to slightly overestimate terminal velocities at diameters below 150 microns and slightly underestimate velocities for diameters above 150 microns. While the agreement between these two curves is not exact, two factors lead to the conclusion that the simple interpolation scheme is quite adequate for the purposes of estimating rain rates. First, the total liquid water contained in these drops is small as the volume is proportional to the third power of the diameter. Second, the velocities themselves are small and therefore the effects of an error in the terminal velocities are also proportionally small.

4 R. C Weast, ed., *CRC Handbook of Chemistry and Physics, 67th Edition*, CRC Press, Inc., Boca Raton, Florida, 1986.

5 F. A. Berry, Jr., E. Bollay, and N. R. Beers, *Handbook of Meteorology*, McGraw-Hill, New York, 1945, Table 52, p. 44.

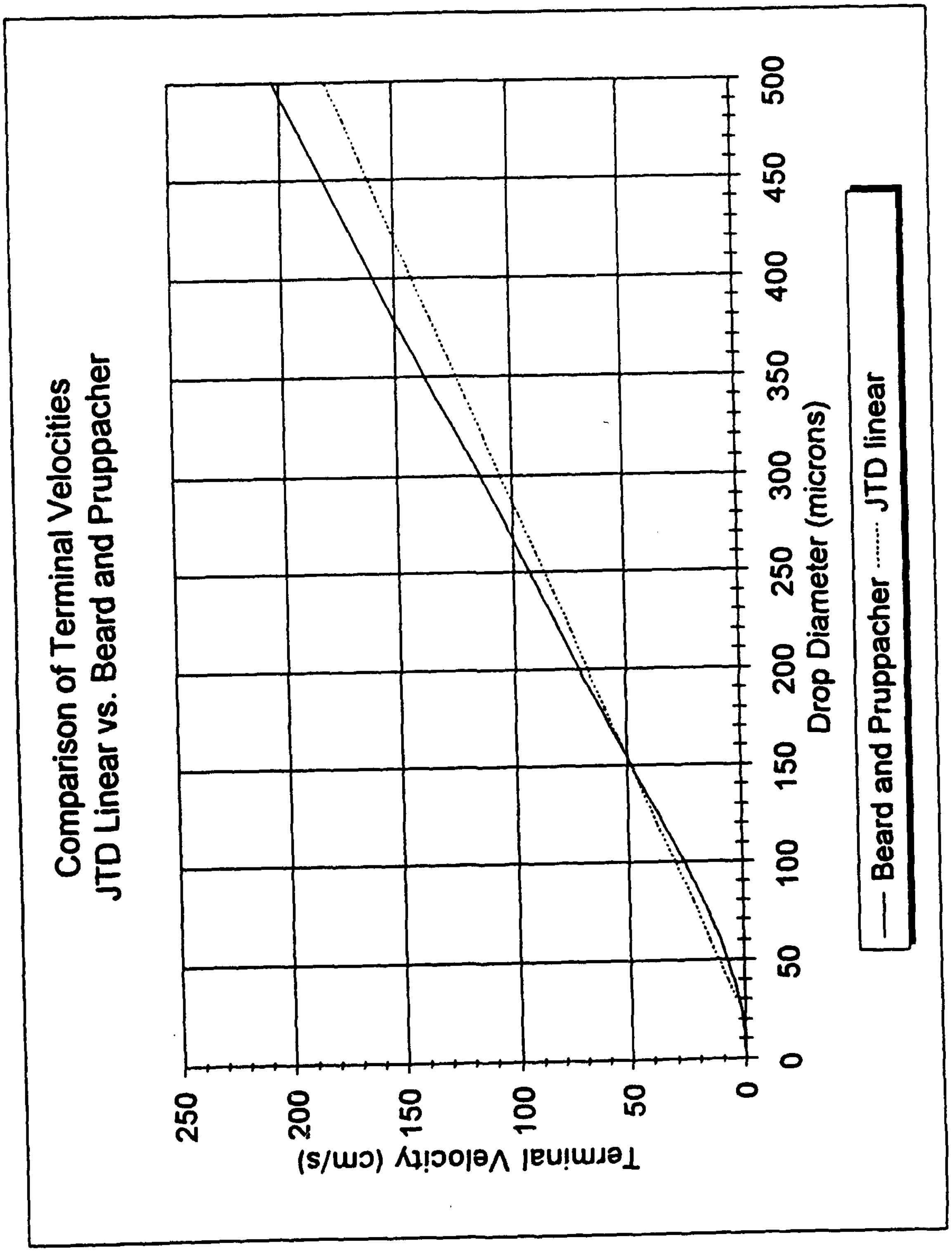

Figure H-1. Beard and Pruppacher and JTD Terminal Velocities

H.2 CALCULATIONS OF BACKSCATTER AND ATTENUATION VALUES FROM PMS PROBE DATA

Using the drop size data collected from the PMS probes, one can calculate both the expected radar backscatter and attenuation from the spectra observed. These calculations are based on the scattering theory of small dielectric spheres formulated initially by Mie[6] as outlined by van de Hulst[7]. Independent scattering theory is used, which assumes that each sphere scatters the incident radiation independently of all other spheres along the path between the radar and the scene. This assumption allows the scattered intensities to be simply summed with one another without regard to the relative phase of the scattered radiation. This assumption is reasonable when the mean distance between particles is greater than 3 particle diameters, an assumption easily made in most of the meteorological conditions experienced in these tests.[8]

A single particle will reduce the intensity of the incident beam of electromagnetic radiation by both scattering and absorbing that radiation. The scattering cross section, C_{sca}, is defined as the area, perpendicular to the direction of the incident beam, which would intercept an amount of energy equal to the total amount of energy scattered in all directions by the particle. The amount of energy absorbed by the particle can, in a similar fashion, be related to an absorption cross section, C_{abs}. Finally, the amount of energy removed from the beam may be related to an extinction cross section, C_{ext}. The conservation of energy requires that the energy removed from the incident beam equal the energy scattered and absorbed. This leads to the following relation between the extinction, scattering, and absorption cross sections

$$C_{ext} = C_{sca} + C_{abs}. \tag{H-28}$$

The extinction efficiency, Q_{ext}, is the ratio of the extinction cross section, C_{ext} to the geometric cross section of the particle. The general form of the extinction of radiation as a function of distance traveled can be expressed as

$$I' = I_0 \, e^{-\alpha d}, \tag{H-29}$$

6 G. Mie, "Beiträge zur Optik trüber Medien, speziell kolloidaler Metallösungen," *Annals of Physics*, Vol. 25, 1908, pp. 377-445.

7 H. C. van de Hulst, *Light Scattering by Small Particles*, Wiley, New York, 1957.

8 H. C. van de Hulst, *Light Scattering by Small Particles*, Wiley, New York, 1957.

where

I' is the attenuated intensity,

I_0 is the incident intensity,

α is the extinction coefficient, and

d is the distance over which the radiation has traveled.

Independent scattering theory assumes that the extinction coefficient per unit length may be expressed as

$$\alpha = \pi\, r^2\, N(r)\, Q_{ext}(r), \tag{H-30}$$

where

r is the radius of the drop,

N(r) is the number density of drops of radius r, and

$Q_{ext}(r)$ is the extinction efficiency for these drops.

The attenuation, in dB per unit length, is derived from Equation H-28 by applying ten times the logarithm to the base ten of both sides. That is

$$10 \log_{10} (I'/ I_0) = 10 \log_{10} (e^{-\alpha d}), \tag{H-31}$$

which may be rewritten as,

$$\mathrm{Att(dB)} = \frac{10 \ln \left(e^{-\alpha d}\right)}{\log_{10}(e)} = 4.343(-\alpha d). \tag{H-32}$$

Substitution of Equation H-30 for α in terms of the extinction coefficient and use of the drop diameter in place of radius, permits this expression to be written as

$$\mathrm{Att(dB)} = -4.343 \; [\; (\pi D^2/4)\; N(D)\; Q_{ext}(D) \;]\; d. \tag{H-33}$$

If N(D) is expressed in number per cubic meter and D is expressed in centimeters squared, the attenuation in dB per kilometer for each size class is found to be

$$\mathrm{Att(dB/km)} = -0.4343\; (\pi D^2/4)\; N(D)\; Q_{ext}(D). \tag{H-34}$$

The total attenuation is then the sum of this quantity over all size classes, that is, the sum over all values of "D."

The computation of backscatter can be developed using the same general equations. The radar backscatter of a single particle can be expressed, using scattering efficiencies similar to those defined in the paragraphs above, as

$$\sigma = 4\,\pi\,r^2\,\frac{S_r}{S_i}, \tag{H-35}$$

where

σ is the backscattering cross section,

r is the radius of the particle, and

S_r and S_i are the backscattered and incident power flux densities respectively.

The form of Equation H-35 leads to the definition of a backscatter efficiency, Q_b as the ratio of S_i to S_r. If the backscatter from a large ensemble of particles is assumed to simply be the sum of the backscatter from each particle within the active volume, V; then the total area normalized backscatter, η, usually referred to as the radar reflectivity, may be written as

$$\eta = \left(\frac{1}{V}\right)\sum_{i=1}^{p} \sigma_i. \tag{H-36}$$

where p is the number of particles.

Substitution from Equation H-35 and use of the backscatter efficiency, Q_b allows this relation to be rewritten as

$$\eta = \Sigma_D\,[\pi D^2\, N(D)\, Q_b(D)\,], \tag{H-37}$$

where the summation is taken over all diameters. The term relating to the total volume has been absorbed into the quantity N(D), which can be seen to be the number density of particles detected of mean diameter, D. The units of this quantity are usually expressed as $m^2\,m^{-3}$ for ground-based scatterers and in cm^{-1} for meteorological targets.

The essential terms, in order to compute the attenuation and the backscatter, are therefore the attenuation and backscatter efficiencies, Q_{ext} and Q_b, respectively. These efficiencies can be calculated using Mie theory. The details of the Mie theory are described in other references.[9] A

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9 H. C. van de Hulst, *Light Scattering by Small Particles*, Wiley, New York, 1957.

FORTRAN computer program was used by GTRI which, using Mie theory, calculated the attenuation and back-scatter efficiencies for spherical particles from input parameters of drop refractive indices, medium refractive indices, radiation wavelength, and drop size. The program calculated the Mie coefficients and efficiencies using the method outlined in Bohren and Huffman.[10] In this method, the numbers of terms required in generating the Bessel function series are determined to obtain convergence without instability. The results from this code have been compared to and agree with a NCAR Technical Note, authored by Warren J. Wiscombe and entitled "Mie Scattering Calculations."[11]

Both the drop size and radar wavelengths to be used in this case are well established. The refractive indices of water, however, are dependent on the temperature of the drops. Several researchers have calculated tables of these indices for various wavelengths and temperatures. Estimates of the attenuation and backscatter are easily calculated using interpolated values from these tables.

For more exact comparisons of the actual sensor performance to expected performance, GTRI calculated refractive indices at the specific temperatures occurring during the tests. An explanation of the methods used in these calculations is presented in the next section.

H.2.1 COMPUTATION OF TEMPERATURE DEPENDENT REFRACTIVE INDICES

Ray[12] has defined a method of calculating the refractive indices of water at any desired temperature. In this method, the dielectric constant, ε', and the loss, ε'', are calculated as a function of temperature using extensions to the Deybe theory. Under this latter theory, the dielectric constant and loss are calculated as functions of the high-frequency dielectric constant, $\varepsilon_\times$, the static constant, ε_s, the frequency of the radiation, λ, the relaxation frequency, λ_s, the frequency-independent conductivity, σ, and the spread parameter, α.

$$\varepsilon' = \varepsilon_\times + ((\varepsilon_s - \varepsilon_\times)[1+ (\lambda_s / \lambda)^{1-\alpha} \sin(\alpha\pi / 2)]) / (1 + 2(\lambda_s / \lambda)^{1-\alpha} \sin(\alpha\pi / 2) + (\lambda_s / \lambda)^{2(1-\alpha)}) \qquad \text{(H-38a)}$$

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10 C. F. Bohren and D. R. Huffman, *Absorption and Scattering of Light by Small Particles*, Wiley, New York, 1983, p. 479.

11 W. J. Wiscombe, "Mie Scattering Calculations," NCAR Tech. Note, NCAR/TN-140+STR, June 1979.

12 Peter S. Ray, "Broadband Complex Refractive Indices of Ice and Water," *Appl. Opt.*, Vol. 11, No. 8, August 1972, pp. 1836-1844.

$$\varepsilon'' = \varepsilon_x + [\,(\varepsilon_s - \varepsilon_x)(\lambda_s / \lambda)^{1-\alpha} \cos(\alpha\pi / 2)\,] /$$
$$[1 + 2(\lambda_s / \lambda)^{1-\alpha} \sin(\alpha\pi / 2) + (\lambda_s / \lambda)^{2(1-\alpha)}\,]$$
$$+ \sigma\lambda / (18.8496 \times 10^{10}) \qquad \text{(H-38b)}$$

Here, only the frequency-independent conductivity is treated as temperature-independent, and is assigned a value of $\sigma = 12.5664 \times 10^8$. The temperature dependence of the other parameters in these equations is expressed as

$$\varepsilon_s = 78.54\,[1.0 - 4.579 \times 10^{-3}\,(T-25.0) + 1.19 \times 10^{-5}$$
$$X\,(T-25.0)^2 - 2.8 \times 10^{-8}\,(T-25.0)^y\,] \qquad \text{(H-39a)}$$

$$\varepsilon_x = 5.27137 + 0.21647\,T - 0.00131198\,T^2 \qquad \text{(H-39b)}$$

$$\alpha = -16.8129 / (T + 273) + 0.0609265 \qquad \text{(H-39c)}$$

$$\lambda_s = 0.00033836 \exp[\,2513.98 / (T+ 273)\,] \qquad \text{(H-39d)}$$

where T is the temperature in degrees C.

The dielectric constant and the loss can then be used to calculate the real and imaginary com-ponents of the complex index of refraction using the following relationships:

$$n_r^2 = (1/2)\,(\varepsilon' \pm (\varepsilon'^2 + \varepsilon''^2\,)\,\Omega \qquad \text{(H-40)}$$

$$n_i^2 = (1/2)\,(-\varepsilon' \pm (\varepsilon'^2 + \varepsilon''^2\,)\,\Omega \qquad \text{(H-41)}$$

For each frequency of interest, these calculations were performed at one-degree temperature increments to produce tables of temperature-dependent refractive indices which could then be used in the calculations of attenuation and backscatter. These temperature-dependent indices were verified against prior published results taken at larger temperature intervals.[13] Plots of the refractive indices at 35 and 95 GHz as functions of temperature are shown below in Figures H-2 and H-3, respectively.

13 S. M. Kupa and E. A. Brown, "Near-Millimeter Wave Technology Base Study," Vol. 1, Harry Diamonds Laboratories, HDL-SR-79-8, November 1979.

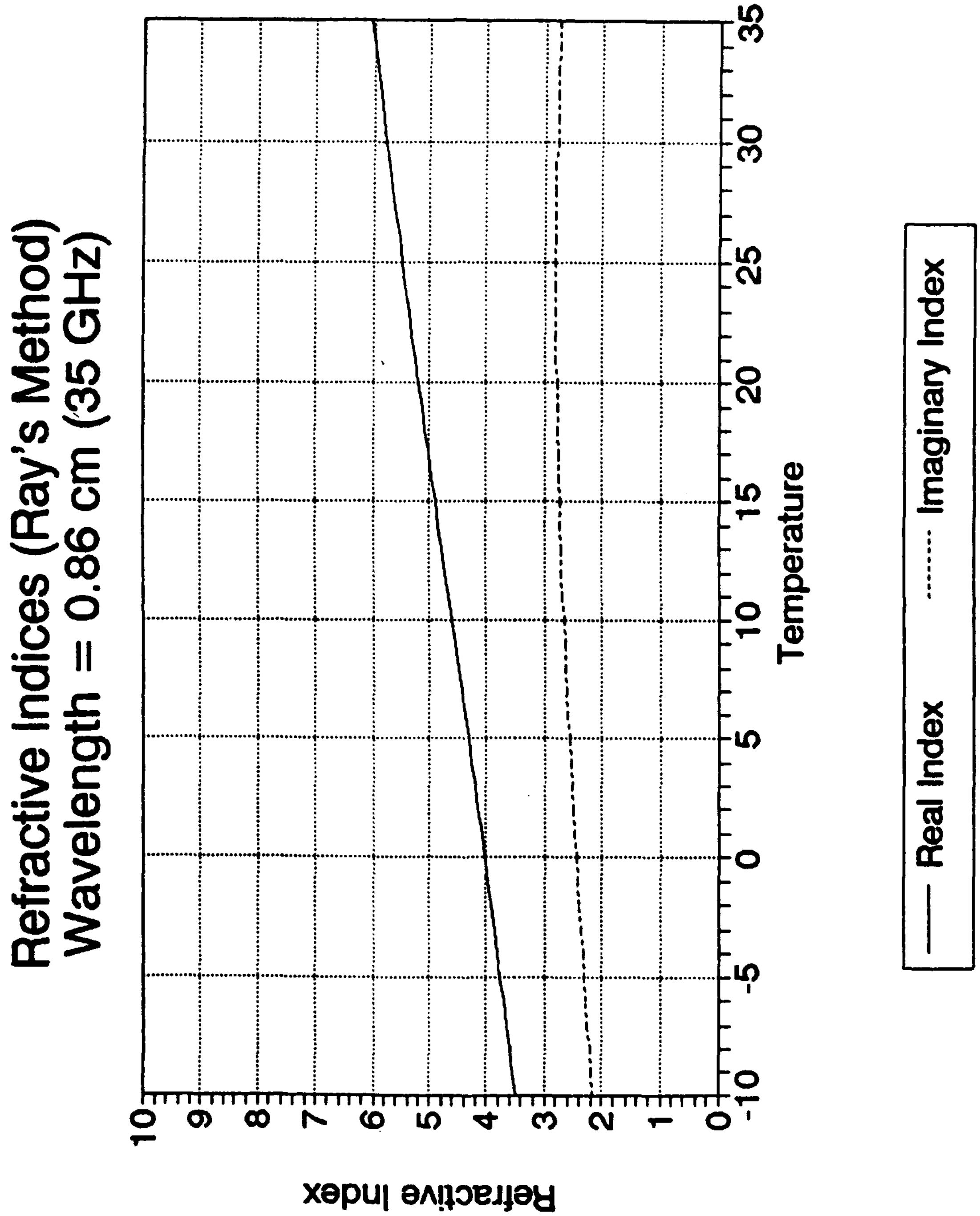

Figure H-2. Refractive Index of water at 35 GHz using the method of Ray

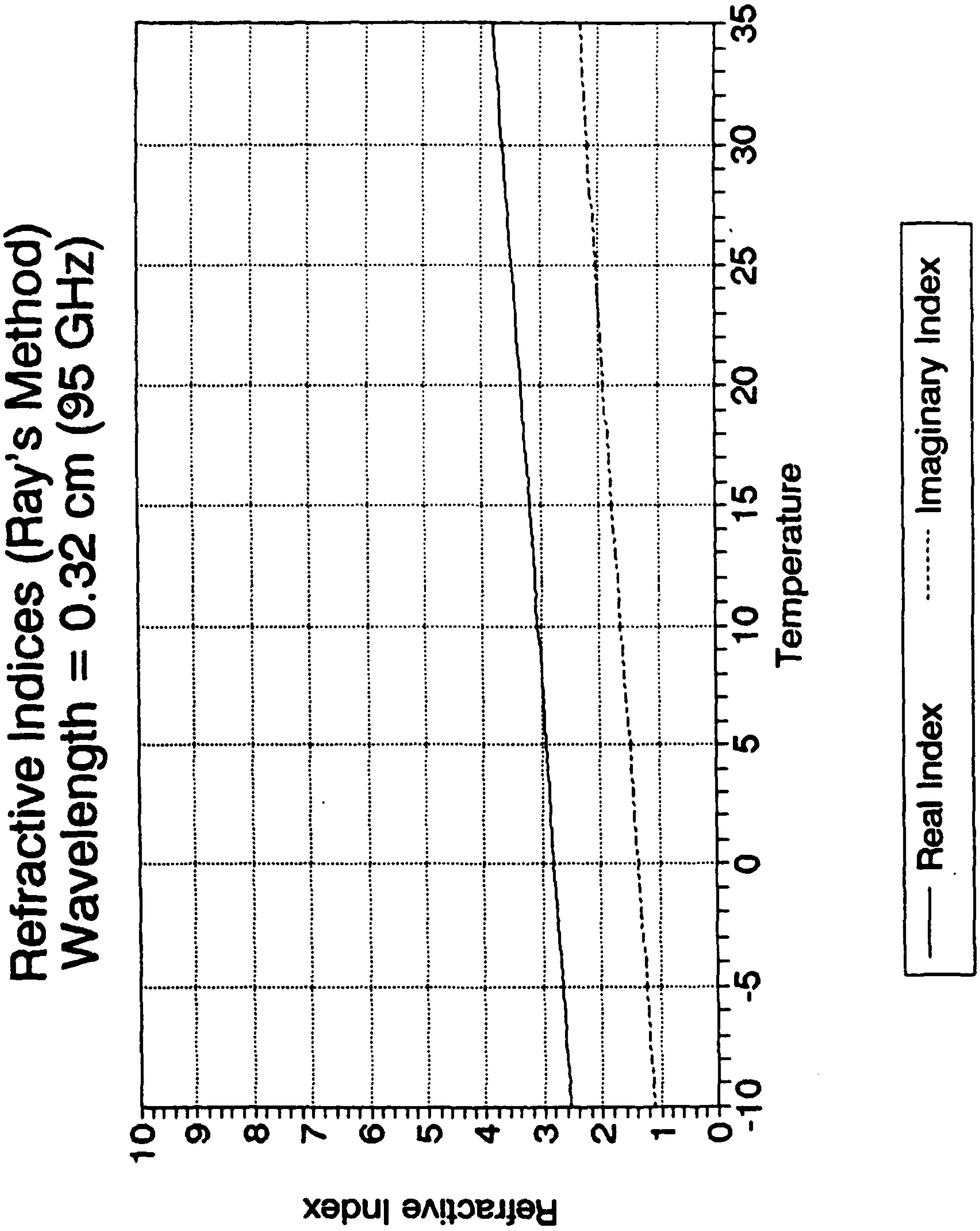

Figure H-3. Refractive Index of water at 95 GHz using the method of Ray

H.2.2 TEMPERATURE-DEPENDENT ATTENUATION CALCULATIONS

The formulas developed in the previous sections were applied to the drop size distributions provided by JTD to calculate attenuation factors. These attenuation factors were then incorporated into the weather data spreadsheet for use as performance evaluation parameters. In order to ease the burden of the calculations, a number of simplifications were made. The simplifications involved the use of a single set of refractive indices for all layers within an approach, and the use of the integrated profile average drop size distributions instead of using individual profile layer distributions. The method used to calculate attenuation values in this manner is described in Section H.2.2.1.

Two sample data sets, one representing a large temperature gradient in a heavy fog and the second representing a heavy rainfall event were used to evaluate the effects of the simplifying assumptions on the calculated attenuation values. Attenuations values for each layer were computed using the temperatures and the drop-size distributions within that layer. These attenuations were then combined, and the combined layer-by-layer attenuations were compared to the integrated profile attenuation values. These calculations are detailed in Section H.2.2.2.

H.2.2.1 Attenuations Calculated from Integrated Drop Size Distributions

The general set of attenuation values included in the weather data spreadsheet was calculated from the integrated drop size distributions. These drop-size distributions were averaged number concentrations taken over the profile layers which included and lay below the aircraft. One can show, in a manner similar to that used to examine the visual range calculations in Section H.1.1, that the use of the integrated values is valid provided the scattering coefficients are independent of the individual profile layers.

The attenuation along the entire path from the aircraft, through the intervening layers, to the ground may be written as

$$A(\mathrm{dB}) = -4.343\,\alpha\,L \qquad \text{(H-42)}$$

where

A is the attenuation is dB,

α is the attenuation coefficient, and

L is the distance over which the radiation travels.

This may be expressed in terms of the number concentrations and scattering coefficients within each layer traversed by the energy as

$$A = -4.343 \sum_{j=1}^{n} \sum_{D} \frac{\pi D^2}{4} N_j(D)\, Q_{ext,j}(D)\, d_j, \qquad \text{(H-43)}$$

where

D is the diameter of the drop,

n is the total number of layers,

$N_j(D)$ is the number concentration of drops of size D in the j^{th} layer,

$Q_{ext,j}(D)$ is the extinction coefficient for drop of size D in the j^{th} layer,

d_j is the thickness of the j^{th} layer, and

the right-hand summation is taken over all drop-size diameters.

The integrated number concentrations can be written as

$$\overline{N}(D) = \frac{\sum_{j=1}^{n} N_j(D)}{n} \qquad \text{(H-44)}$$

which may be rewritten as

$$\sum_{j=1}^{n} N_j(D) = n\, \overline{N}(D) \qquad \text{(H-45)}$$

If the assumption is made that the scattering coefficients are layer independent and if each layer is the same depth, we may rewrite Equation H-43 as

$$A = -4.343 \sum_{j=1}^{n} \sum_{D} \frac{\pi D^2}{4} N_j(D)\, Q_{ext}(D) d, \qquad \text{(H-46)}$$

where $Q_{ext}(D)$ and d are now independent of the layer index.

The summations over layer j, and drop size D, may now be interchanged and the factors $Q_{ext}(D)$ and d may be brought out of the layer sum to yield

$$A = -4.343\,\frac{\pi}{4}\,d \sum_D D^2\,Q_{ext}(D)\left[\sum_{j=1}^{n} N_j(D)\right]. \qquad \text{(H-47)}$$

If a final substitution is made for the sum of $N_j(D)$ in terms of the integrated number concentration $\overline{N}(D)$, and the total path length, L, is used, the form of the equation used to evaluate the integrated attenuation factors is

$$A = -4.343\,\frac{\pi}{4}\,L \sum_D D^2\,Q_{ext}(D)\,\overline{N}(D)\,. \qquad \text{(H-48)}$$

H.2.2.2 Temperature Dependent Level by Level Attenuation Calculations

Several approaches during the course of the flight tests where observed to contain substantial temperature gradients. The method of calculating attenuations outlined in Section H.2.2.1, however, assumes that the scattering coefficients are independent of height. Two test cases were evaluated to determine the magnitude of error caused by this assumption. The first test case involved a steep temperature gradient during a heavy fog event, in which the temperature varied 7 degrees over a height of 2220 meters. The second test case involved a less dramatic temperature gradient, only 3 degrees over 3600 meters, but took place during a heavy rain event when attenuations were expected to be substantial. Attenuations calculated using the integrated number concentrations were compared with attenuations calculated by using Equation H-43 evaluated at each level and using scattering coefficients appropriate for the temperature found in those individual layers. The results of this comparison are tabulated in Table H-2 below.

Within Table H-2, the reported attenuation values were computed based on Equation H-48 and the integrated number concentrations. The reported average denotes the average attenuation computed for all data snapshots from all approaches in sortie 1 on 8/28 (top) and in sortie 1 on 9/25 (bottom). The reported maximum is the maximum computed value from each set. The average and maximum percent differences were computed based on a case-by-case comparison of the attenuation values computed via the two different methods. Data for each of the two probes are presented.

Table H-2. Comparison of Attenuation Values Computed by Two Different Methods

			Attenuation (dB/km)		Percent Difference	
Date	Weather	Probe	Average	Maximum	Average	Maximum
08/28	Fog	FSSP	0.199	0.447	0.004	0.02
		OAP	0.046	0.128	0.005	0.03
09/25	Rain	FSSP	0.035	0.155	0.0018	0.023
		OAP	2.56	7.05	0.0035	0.025

One can see from Table H-2 that there was very little difference between the attenuations calculated using the temperature-dependent layer-by-layer method and those calculated using the integrated values. The maximum difference found in the calculated attenuation between a layer and the ground using the two methods was only 0.02 percent. The average difference found between attenuations calculated by the two different methods was an order of magnitude less than this. On the basis of these results, one can reasonably use the attenuation calculation method based on the integrated number concentrations for all but the most demanding analysis efforts.

H.2.3 BACKSCATTER CALCULATED FROM INTEGRATED DROP SIZE DISTRIBUTIONS

Backscatter from the fog and rain droplets may be calculated using similar formulae as were developed previously in Section H.2. The formula for backscatter from an individual layer is

$$B = \sum_D N(D) Q_{bck}(D), \qquad \text{(H-49)}$$

where

B is the backscatter from the layer in m^2 per cubic meter,

N(D) is the number concentration within the layer, and

$Q_{bck}(D)$ is the backscatter coefficient for a drop of size D within the layer.

The summation is taken over all drop-sizes, D. The backscatter from a series of layers, each of depth d, may be calculated by simply averaging the backscatter from the individual layers if independent scattering is assumed. This yield the expression

$$B = \frac{1}{d} \sum_{j=1}^{L} \sum_{D} [N_j(D)\, Q_{bck,j}(D)], \tag{H-50}$$

where

$N_j(D)$ and $Q_{bck,j}(D)$ now depend on both the drop size and the layer in which they lie, and L denotes the number of layers.

Again, the assumption that the Q_{bck} values are independent of layer yields a much simpler equation which can use the integrated drop size distributions

$$B = \frac{1}{d}\, \overline{N}(D) \sum_{D} [Q_{bck}(D)]\,. \tag{H-51}$$

H.2.4 Temperature Dependent Level by Level Backscatter Calculations

The same test cases used to evaluate the effects of temperature gradients and high rain rates on the attenuation calculations in Section H.2.2.2 were used to evaluate the relative accuracy of the simplified backscatter calculation. Backscatter calculations were performed at each level along the profiles with Equation H-50, using individual layer number concentrations and temperatures; and then repeated with Equation H-51, using the integrated values for temperature and number concentration. The results of this comparison are provided in Table H-3 below.

Table H-3. Comparison of Volumetric Reflectivity (backscatter) Values Computed by Two Different Methods

		Backscatter			Percent Difference	
Date	PMS Probe	Average (dB)	Maximum (dB)	Average (linear)	Average (linear)	Maximum (linear)
08/28	FSSP	-107	-102	-106	0.003	0.019
	OAP	-94	-88	-94	0.004	0.017
09/25	FSSP	-111	-107	-110	0.002	0.021
	OAP	-44	-36	-41	0.003	0.018

Within Table H-3, the reported backscatter values were computed based on Equation H-51 and use of the integrated values for temperature and number concentration. The average (dB)

denotes the average backscatter computed in log-space for all data snapshots from all approaches in sortie 1 on 8/28 (top) and all approaches in sortie 1 on 9/25 (bottom). The reported maximum is the maximum backscatter computed for all of the snapshots. The reported average (linear) represents the average backscatter computed via a linear (not dB) averaging operation. The reported average (dB) was computed based on an average of logarithmic values. The average and maximum percent differences were computed based on a case-by-case comparison of the backscatter values computed via the two different methods.

Again, little difference can be found in the backscatter values produced using the simplified equation and those computed more rigorously. The average difference between the backscatter values calculated using the two methods was less than or equal to 0.004 percent. The maximum difference between the two methods was less or equal to 0.021 percent. Thus, the simplified analysis based on Equation H-51 and using the integrated values for temperature and number concentration is certainly accurate enough for this application.

APPENDIX I

DATA ACQUISITION TRANSFER CURVE DATA

Figures I-1 through I-11 plot the measured and calculated data acquisition system transfer function for selected gain/bias settings. The calculated functions are based on the original Honeywell equations describing the video amplifier transfer function (Equations 4.4.2-1 through 4.4.2-3 of Volume 3). Figures I-12 through I-22 plot the same measured data as before, but the corresponding calculated values are generated based on the modified video amplifier transfer function developed by GTRI (Equations 4.4.2-5 through 4.4.2-7 of Volume 3).

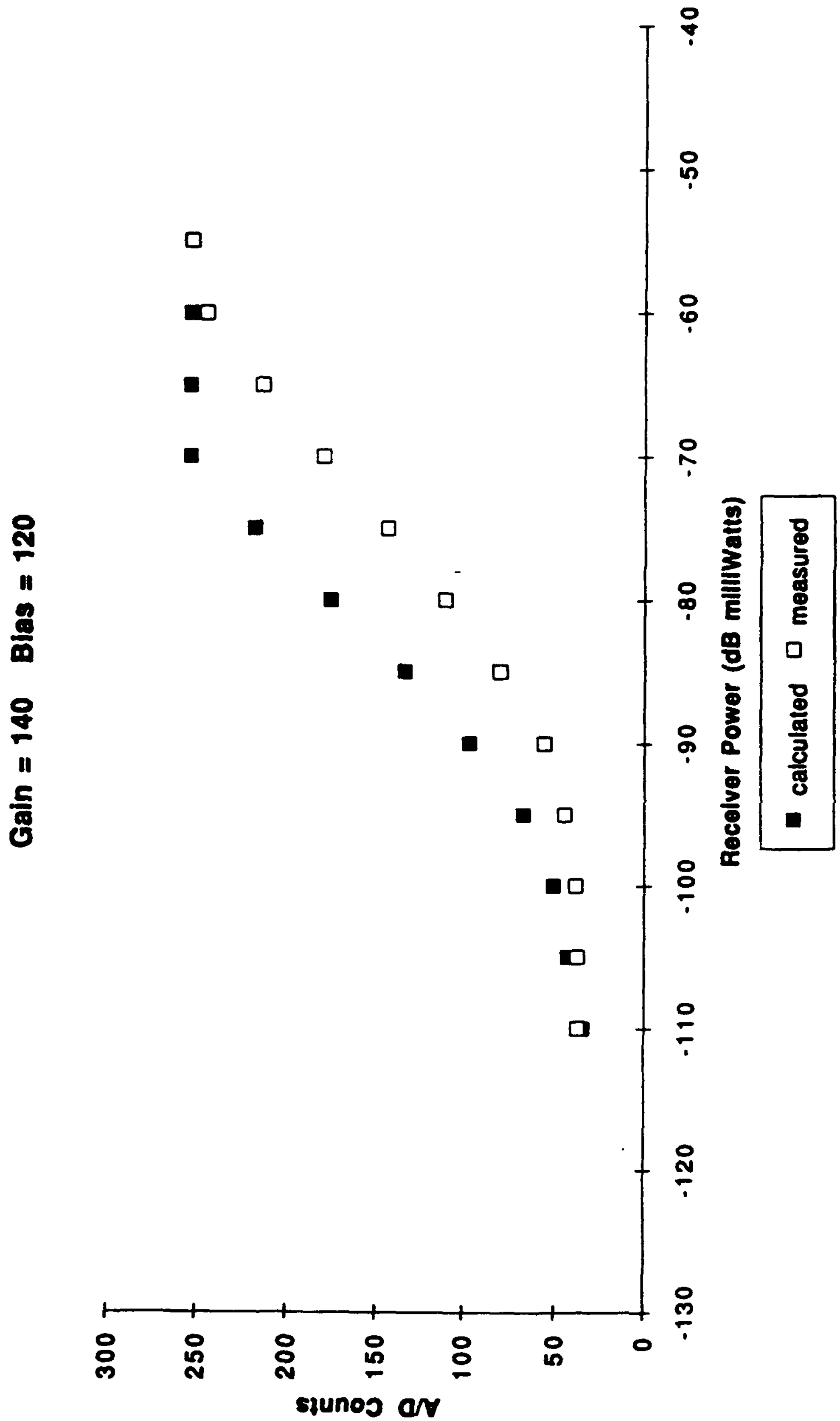

Figure I-1. Data Acquisition System Transfer Function for Gain/Bias = 140/120

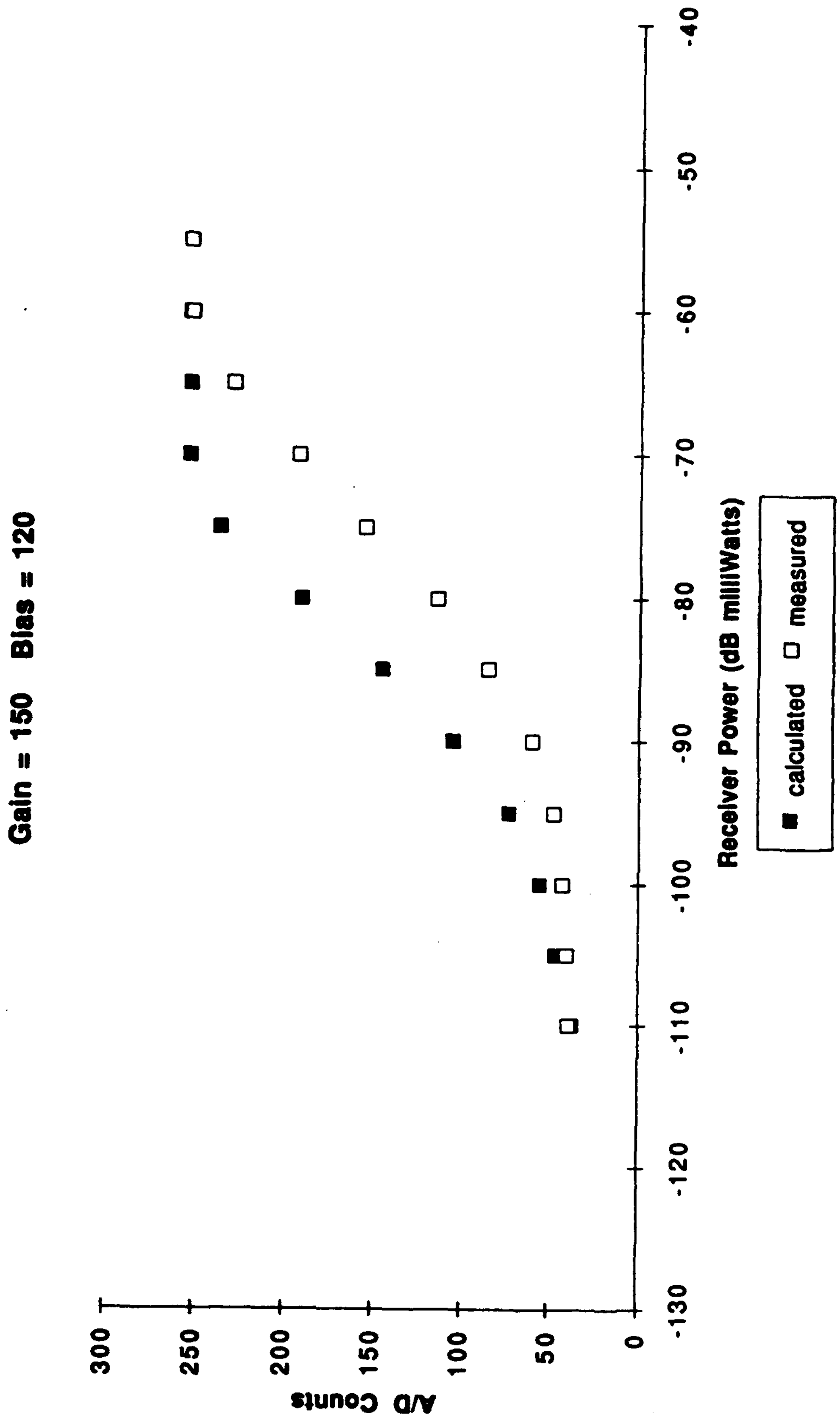

Figure 2. Data Acquisition System Transfer Function for Gain/Bias = 150/120

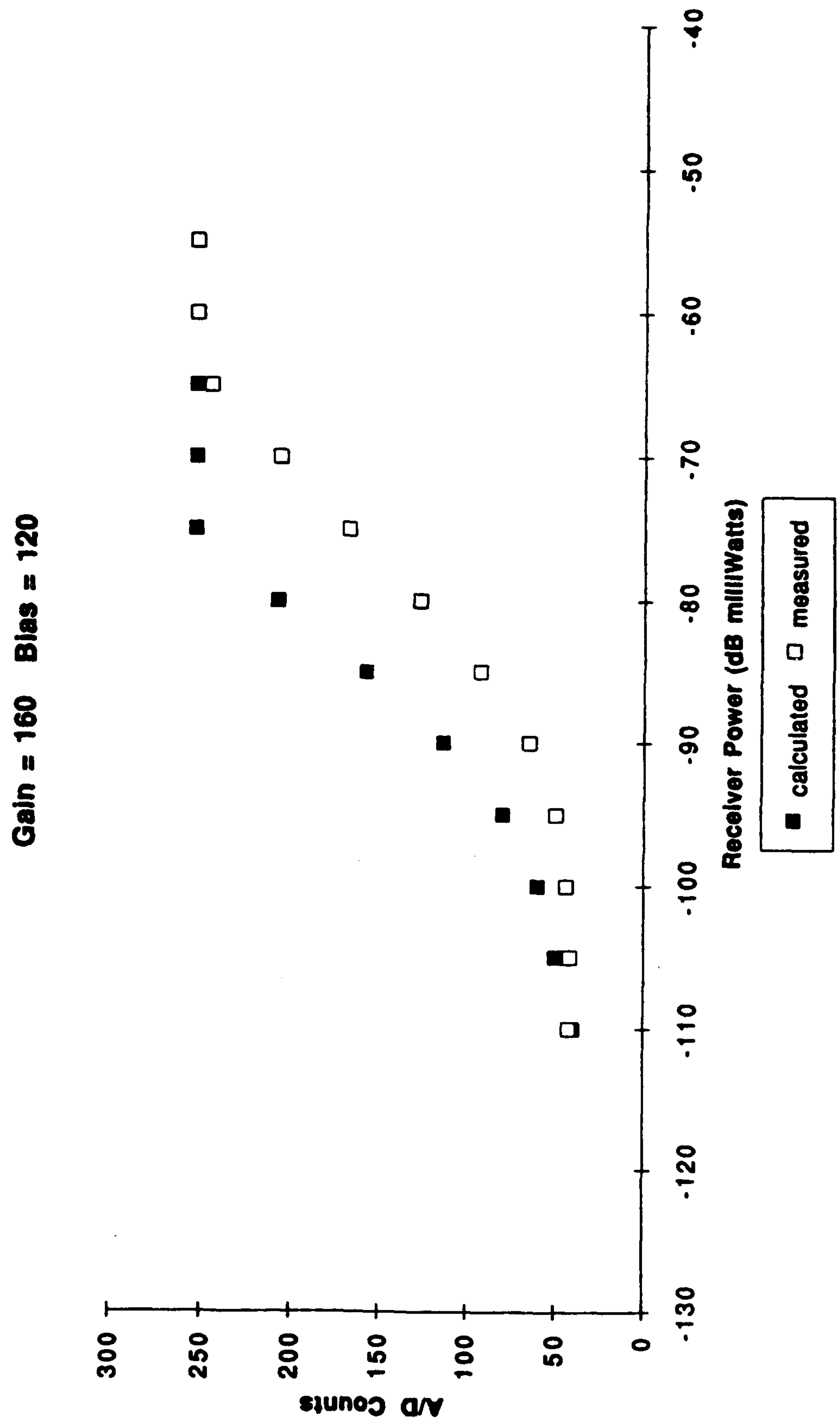

Figure I-3. Data Acquisition System Transfer Funct Gain/Bias = 160/120

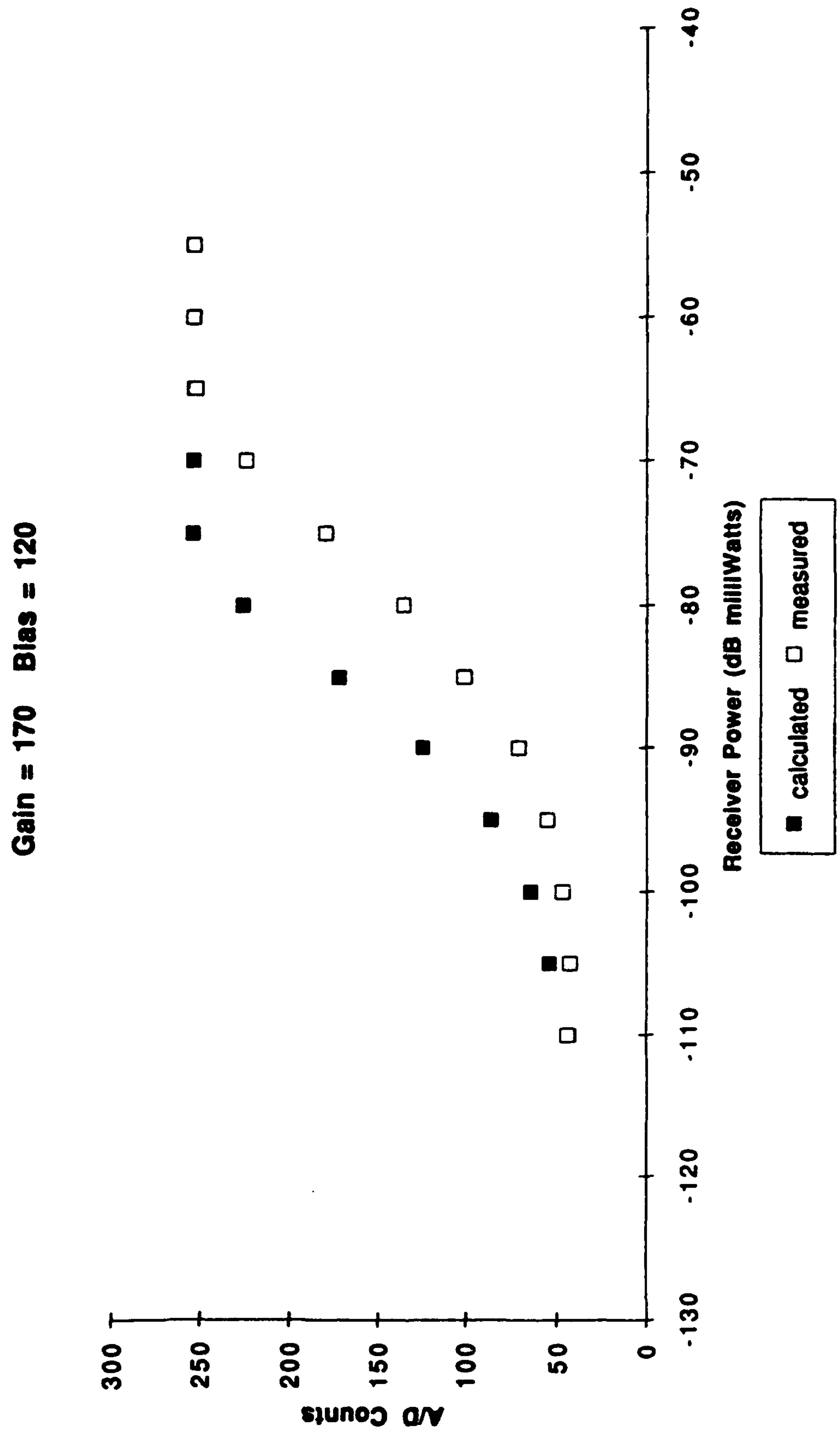

Figure I-4. Data Acquisition System Transfer Function for Gain/Bias = 170/120

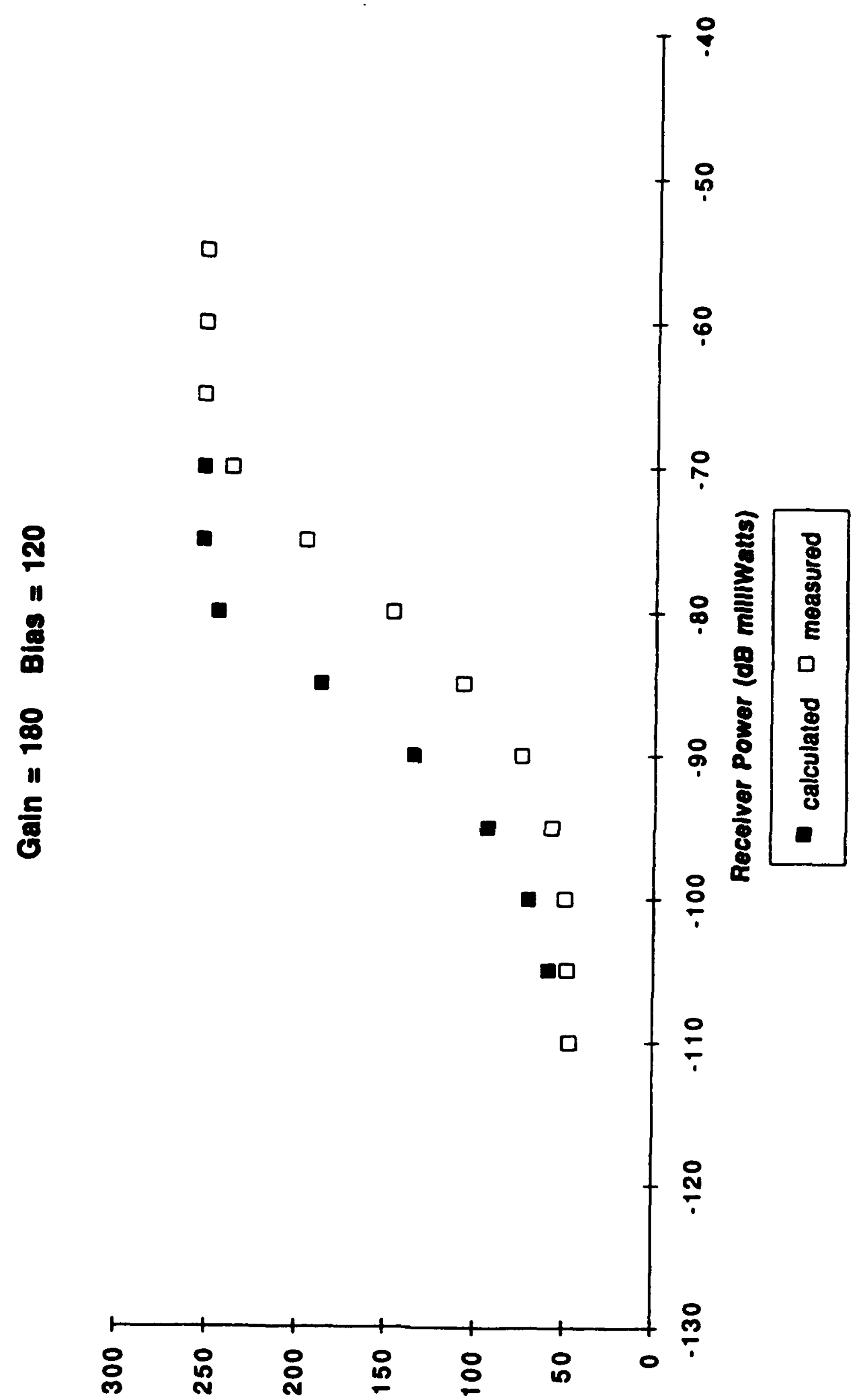

Figure I-5. Data Acquisition System Transfer Function for Gain/Bias = 180/120

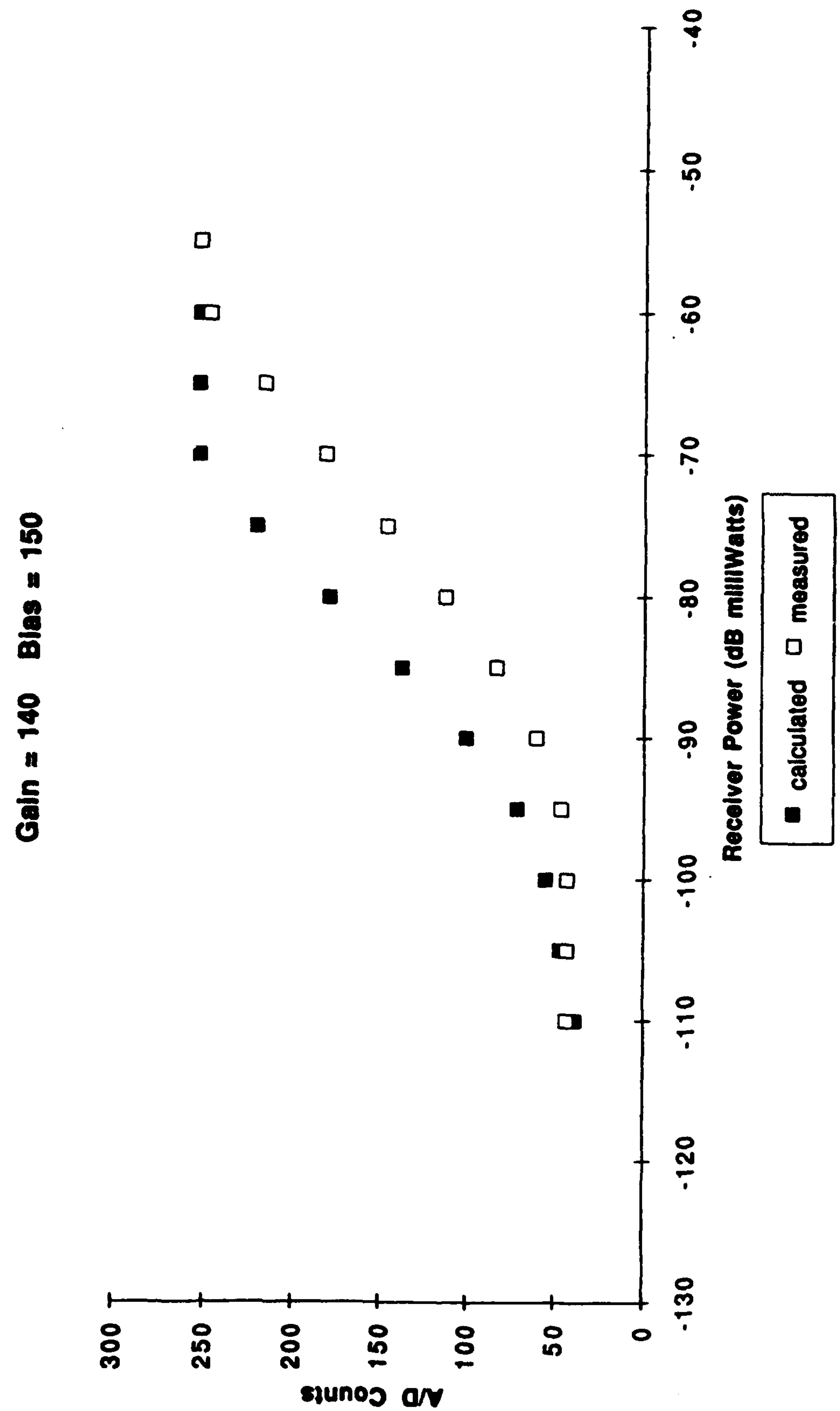

Figure I-6. Data Acquisition System Transfer Function for Gain/Bias = 140/150

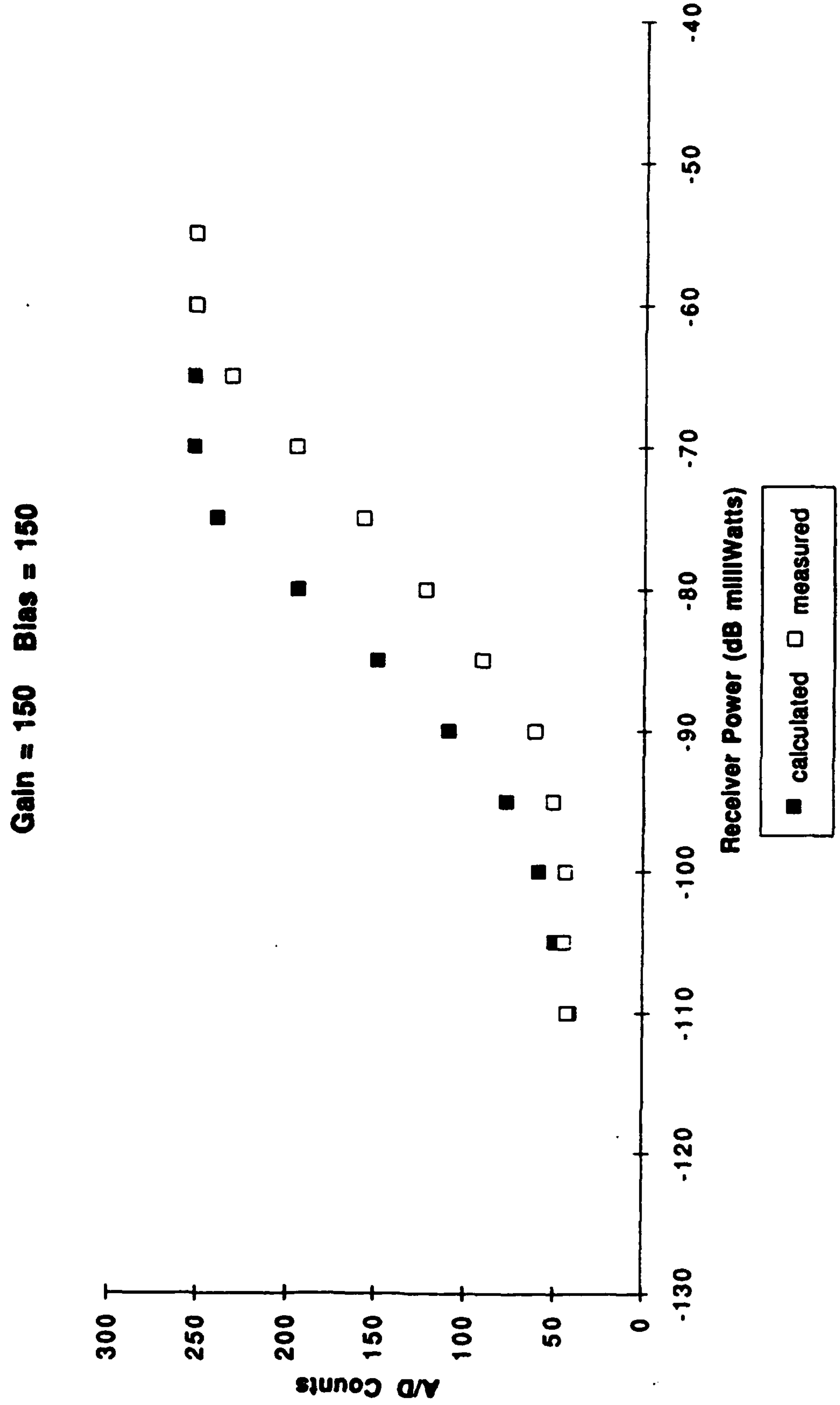

Figure I-7. Data Acquisition System Transfer Function for Gain/Bias = 150/150

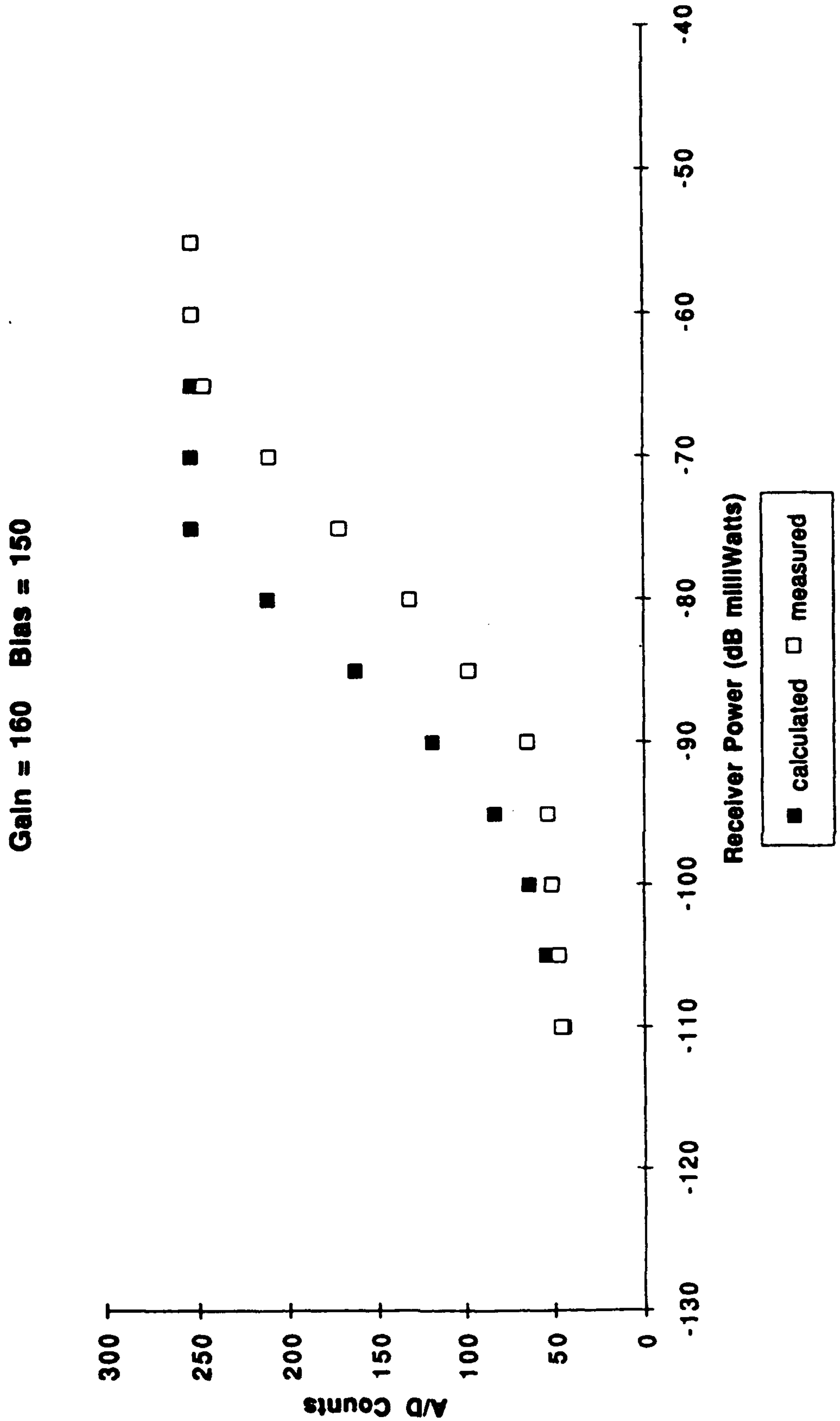

Figure I-8. Data Acquisition System Transfer Function for Gain/Bias = *160/150*

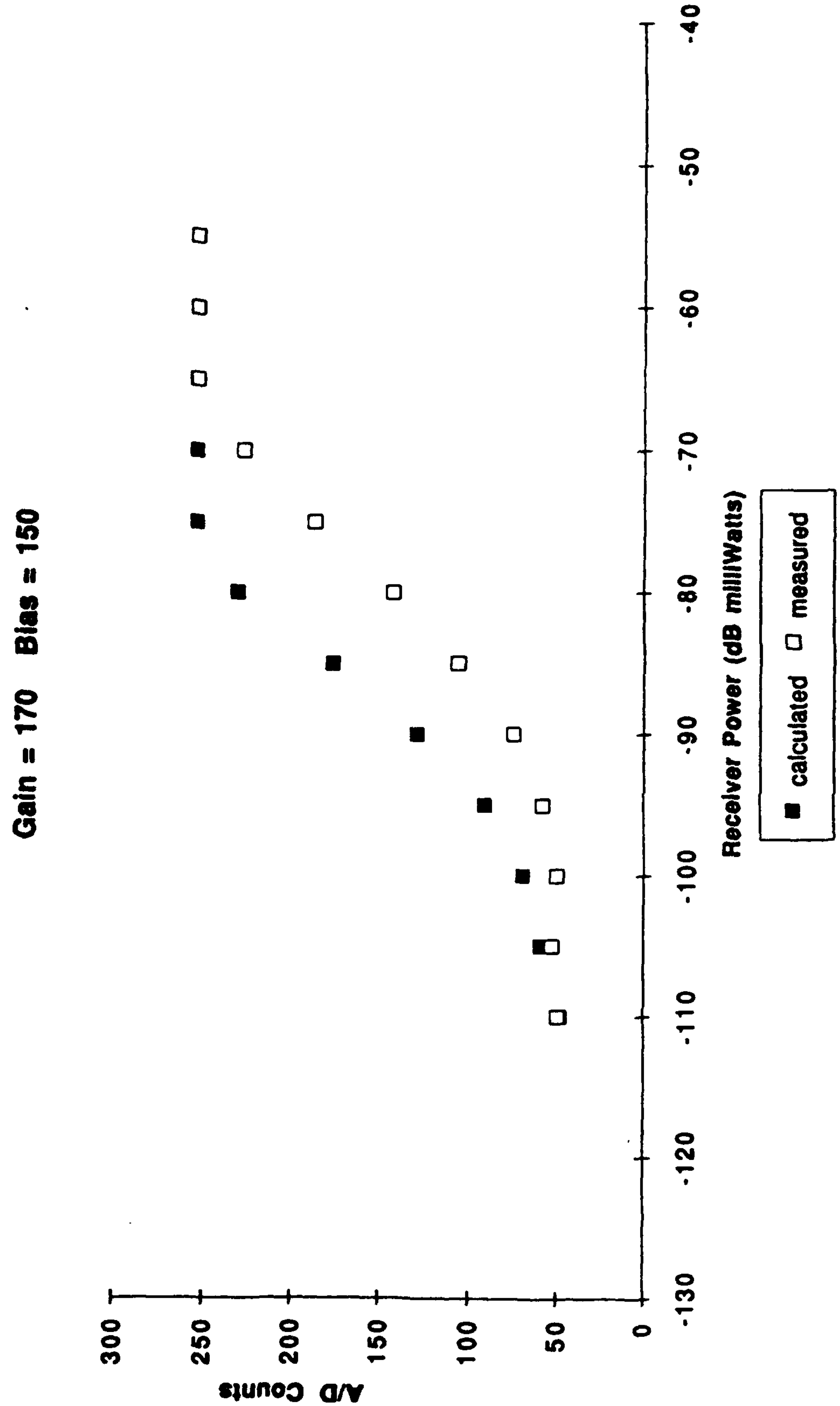

Figure I-9. Data Acquisition System Transfer Function for Gain/Bias - 170/150

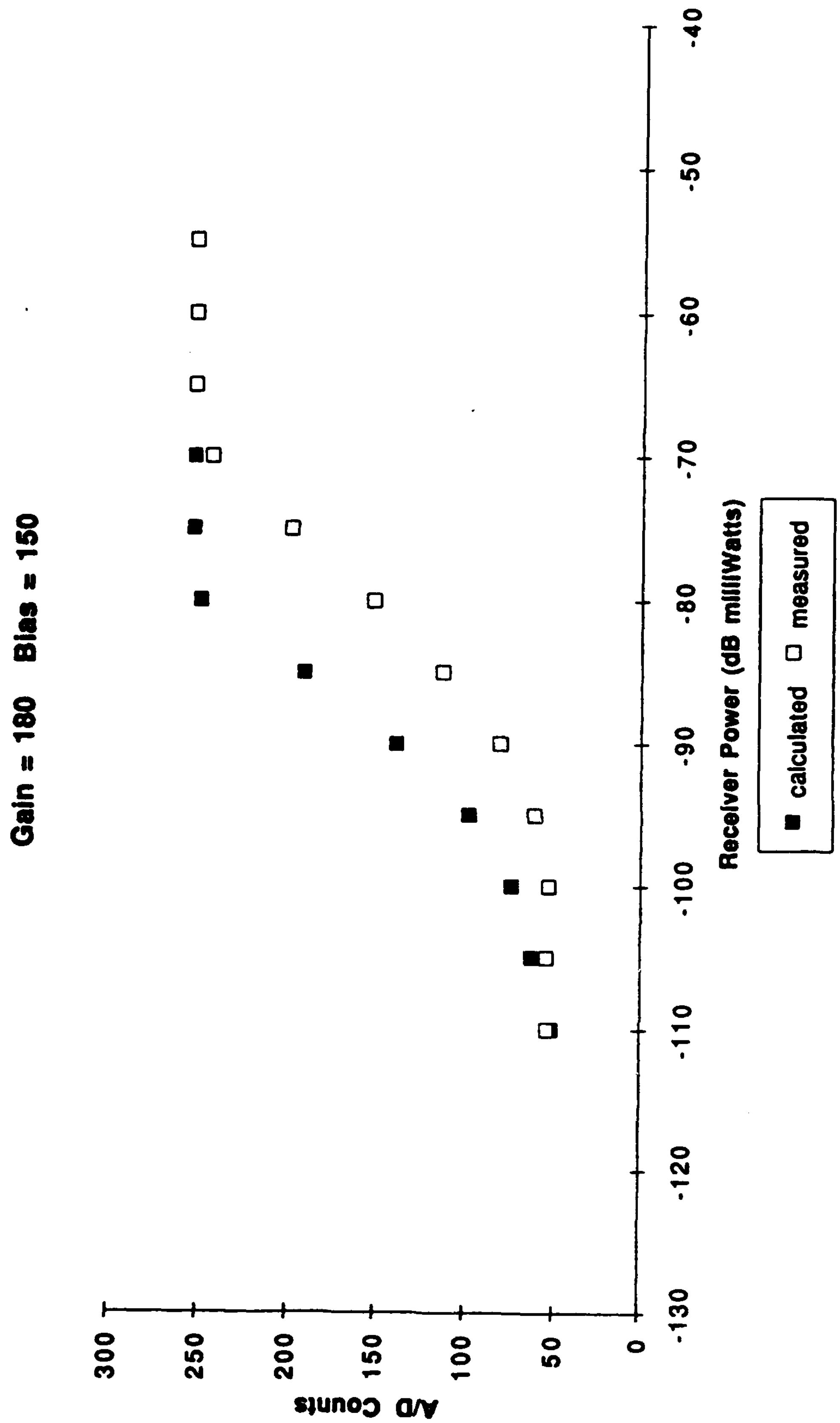

Figure I-10. Data Acquisition System Transfer Function for Gain/Bias = 180/150

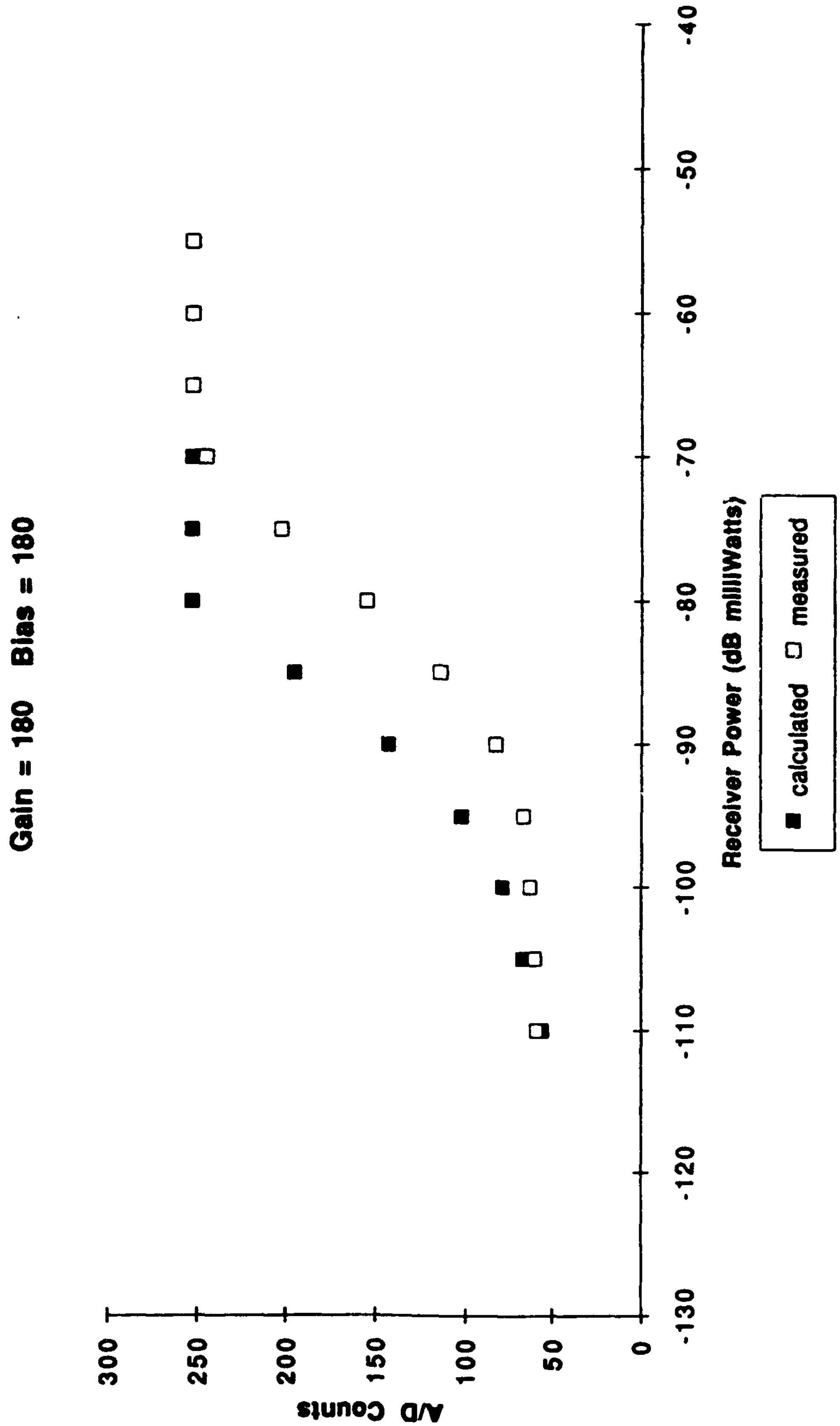

Figure I-11. Data Acquisition System Transfer Function for Gain/Bias = 180/180

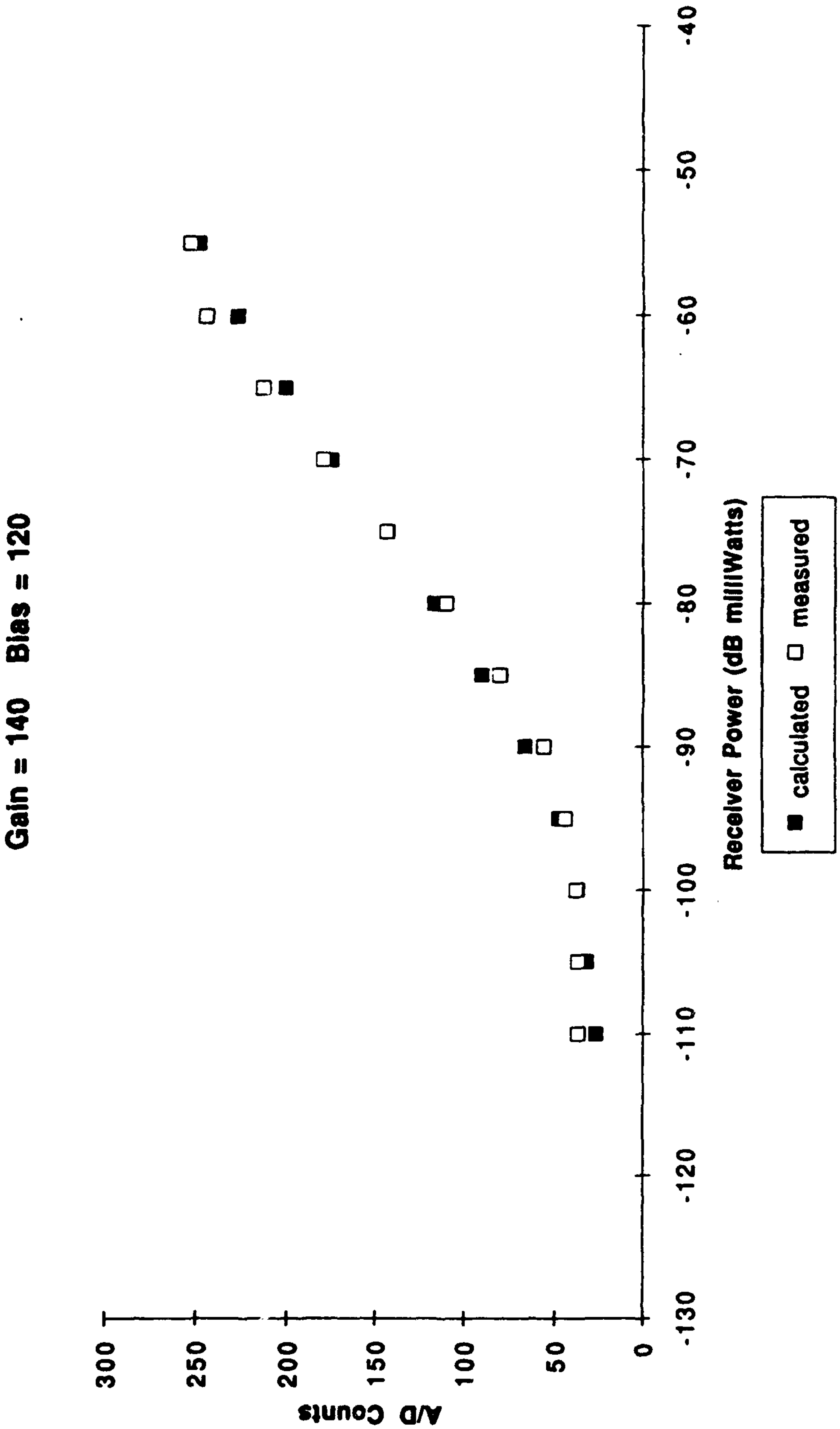

Figure 12. Data Acquisition System Transfer Function for Gain/Bias = 140/120

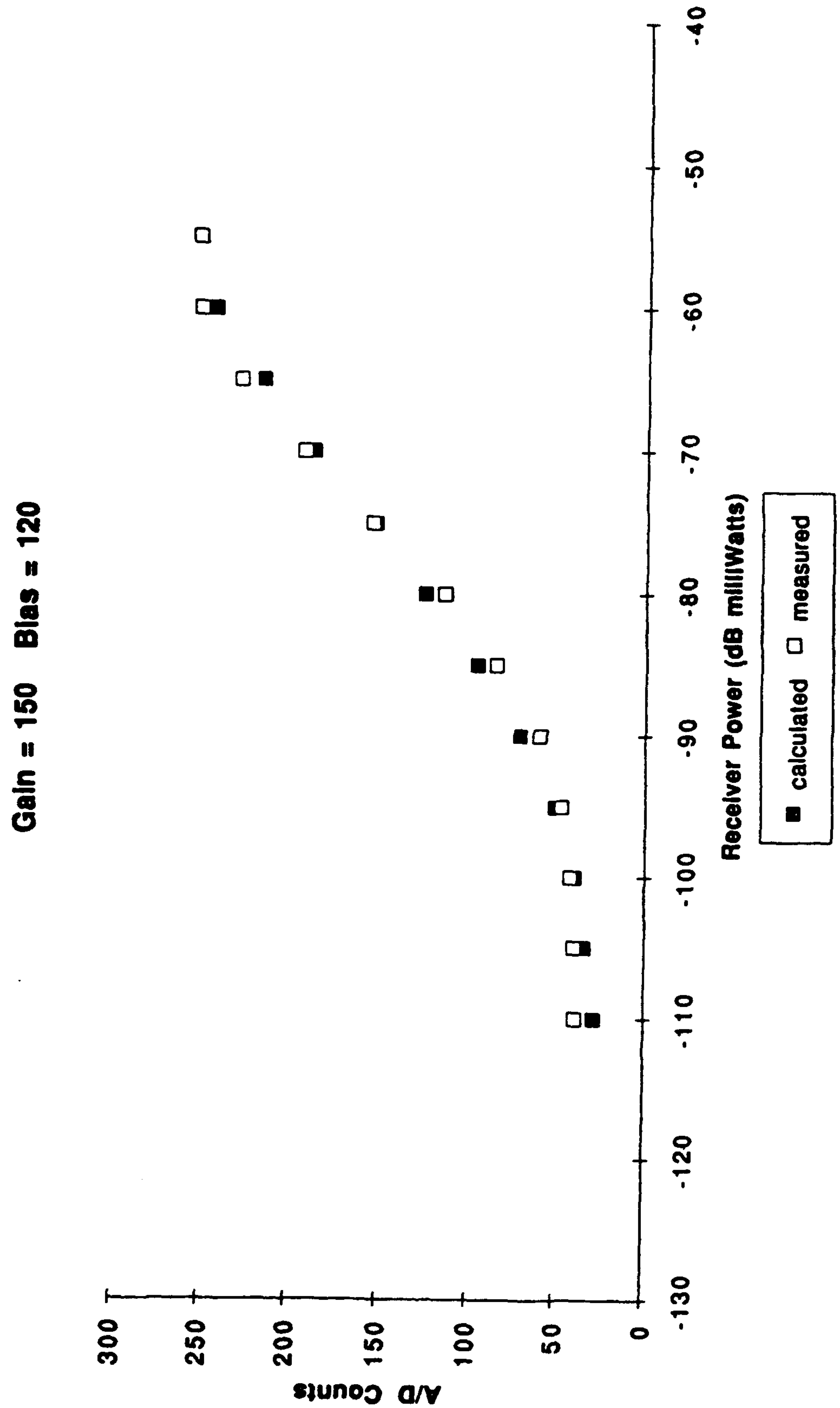

Figure I-13. Data Acquisition System Transfer Function for Gain/Bias = 150/120

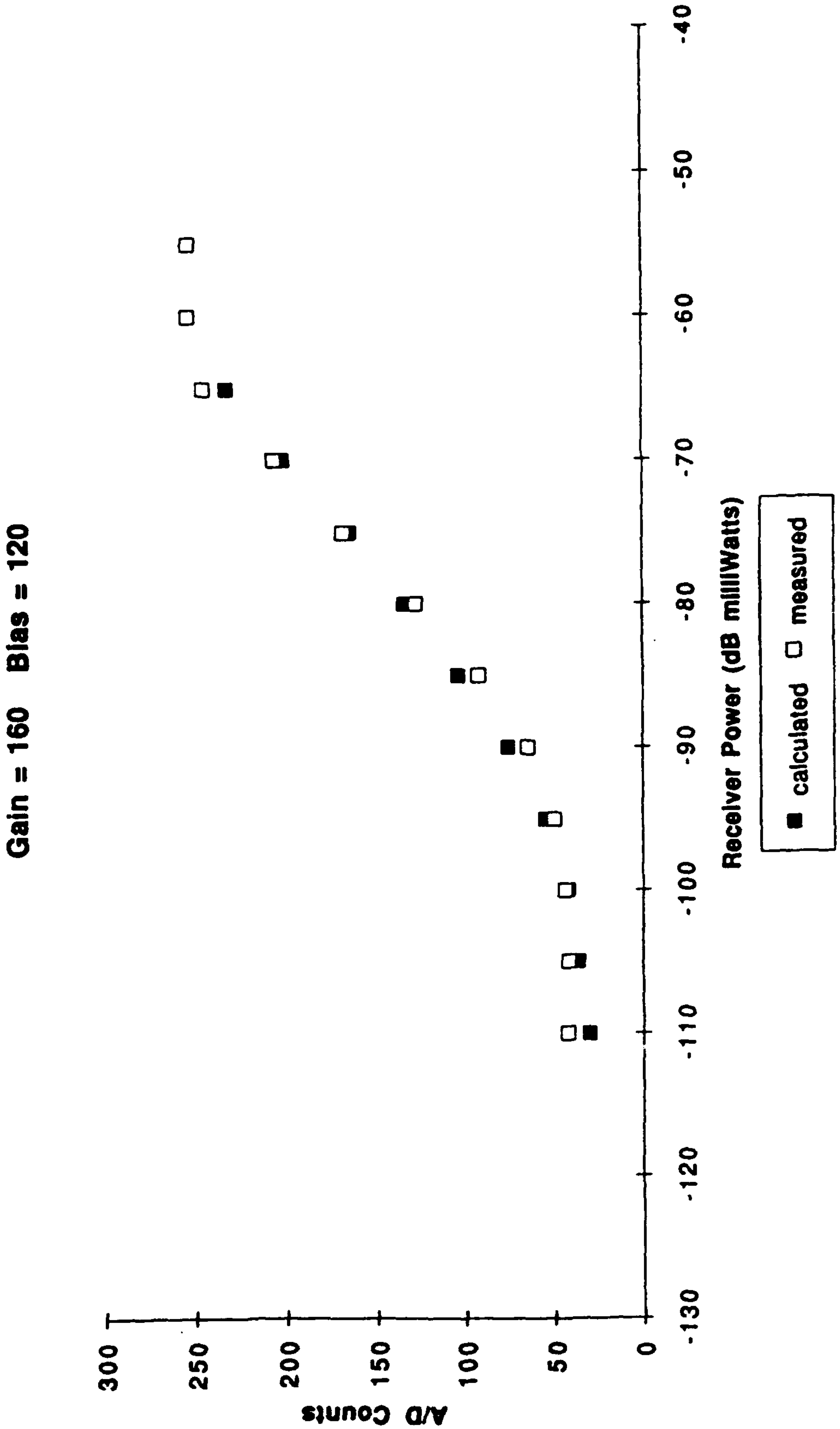

Figure I-14. Data Acquisition System Transfer Function for Gain/Bias = 160/120

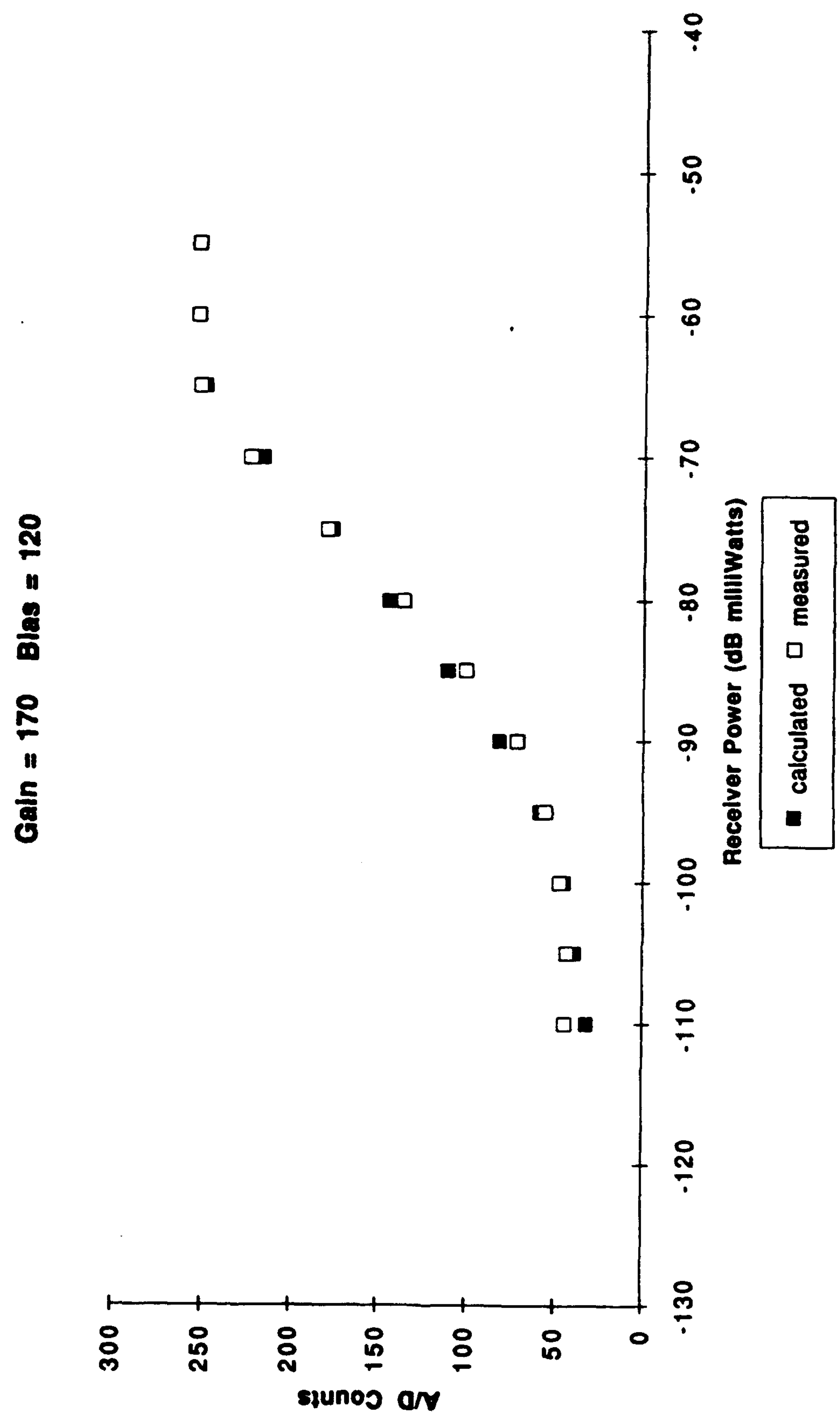

Figure I-15. Data Acquisition System Transfer Function for Gain/Bias = 170/120

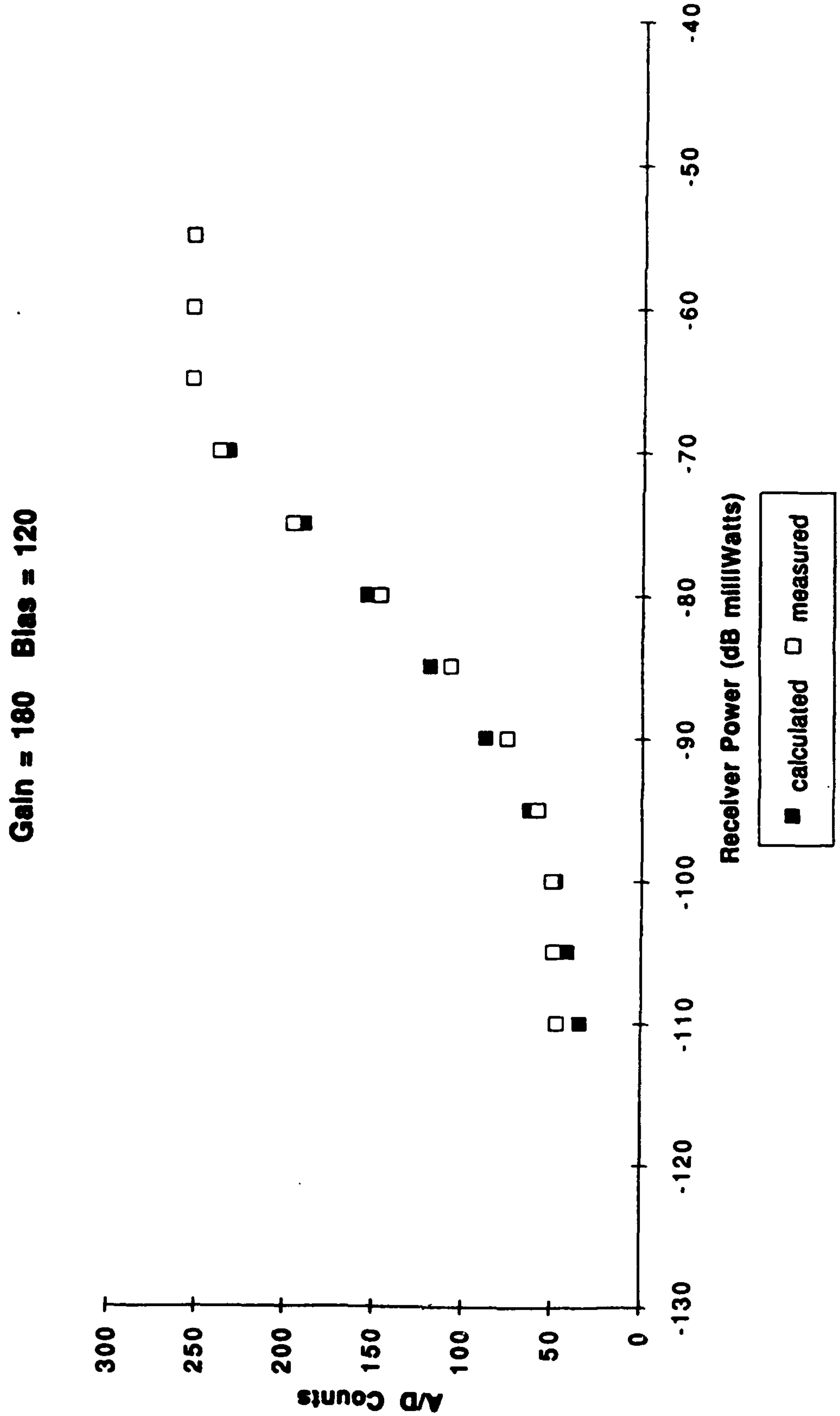

Figure I-16. Data Acquisition System Transfer Function for Gain/Bias = 180-120

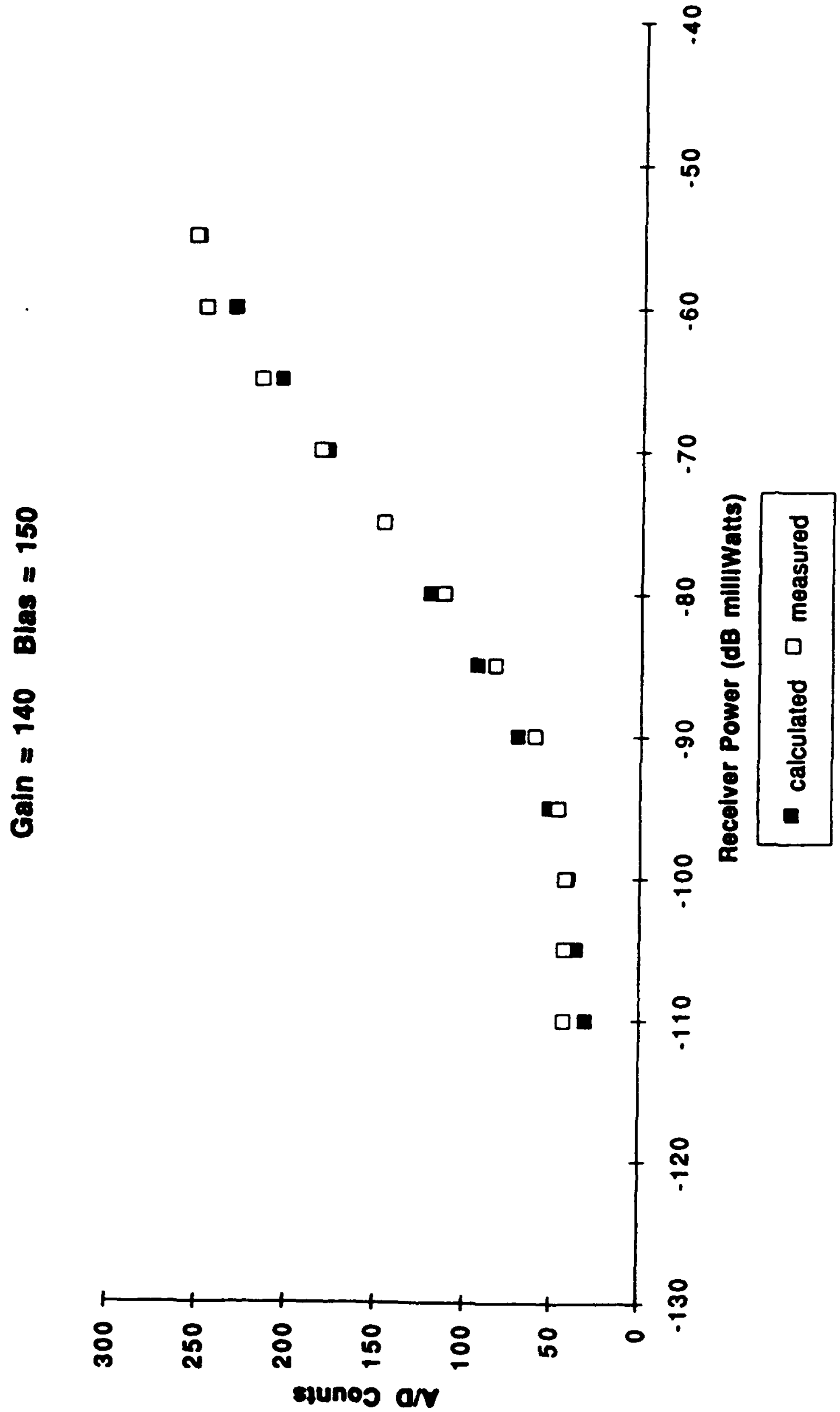

Figure - I-17. Data Acquisition System Transfer Function for Gain/Bias = 140/150

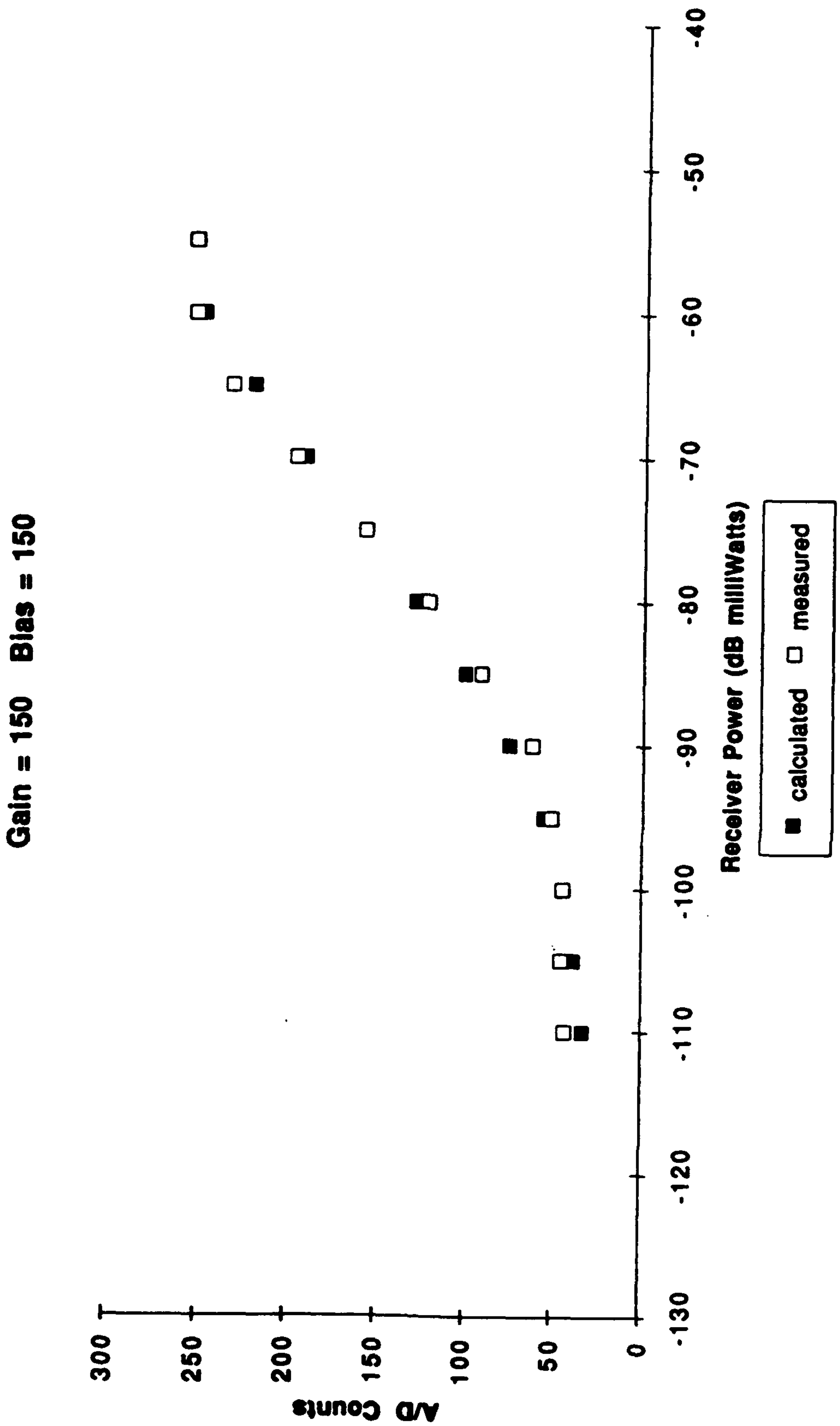

Figure I-18. Data Acquisition System Transfer Function for Gain/Bias = 150/150

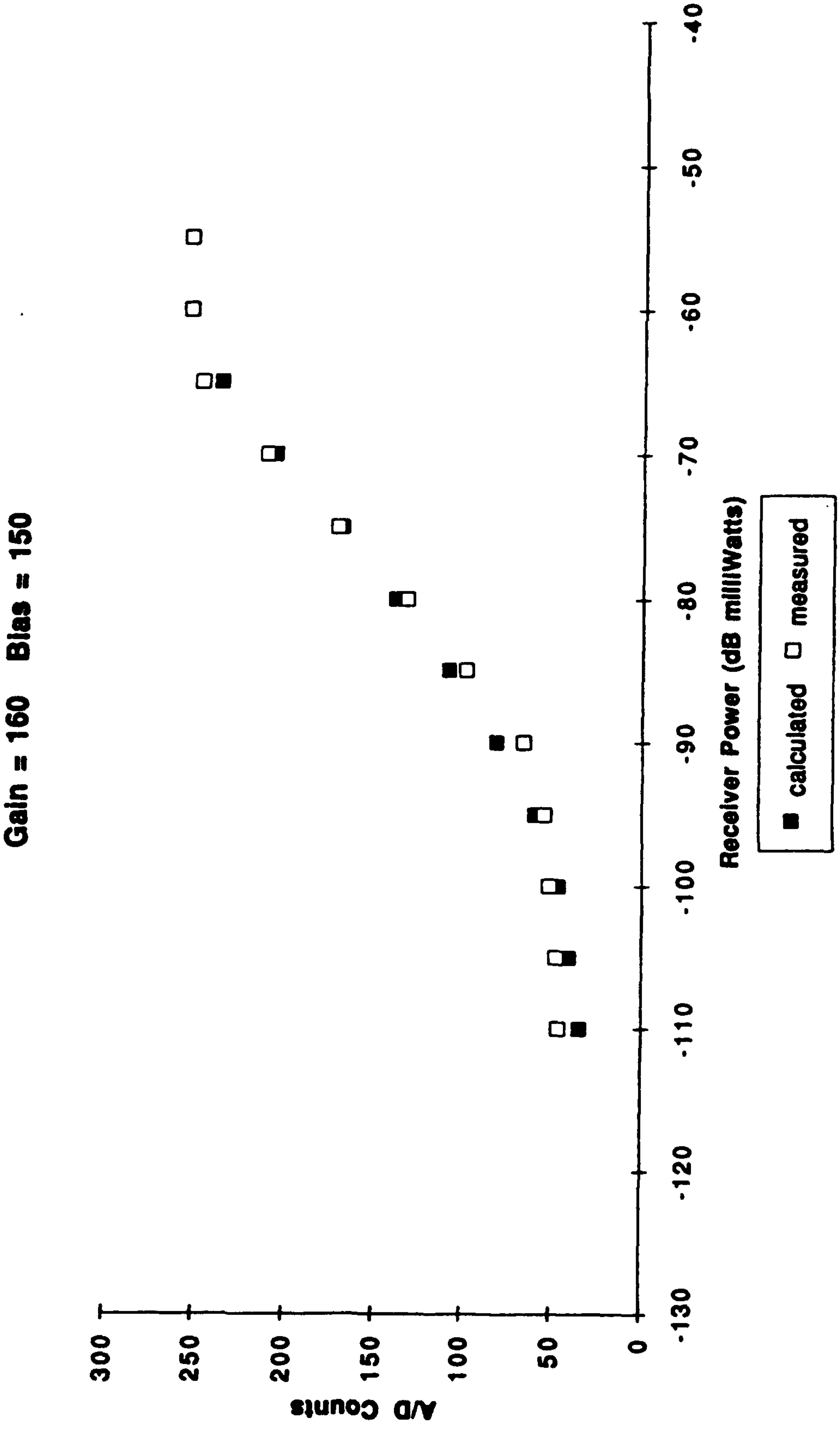

Figure I-19. Data Acquisition System Transfer Function for Gain/Bias of 160/150

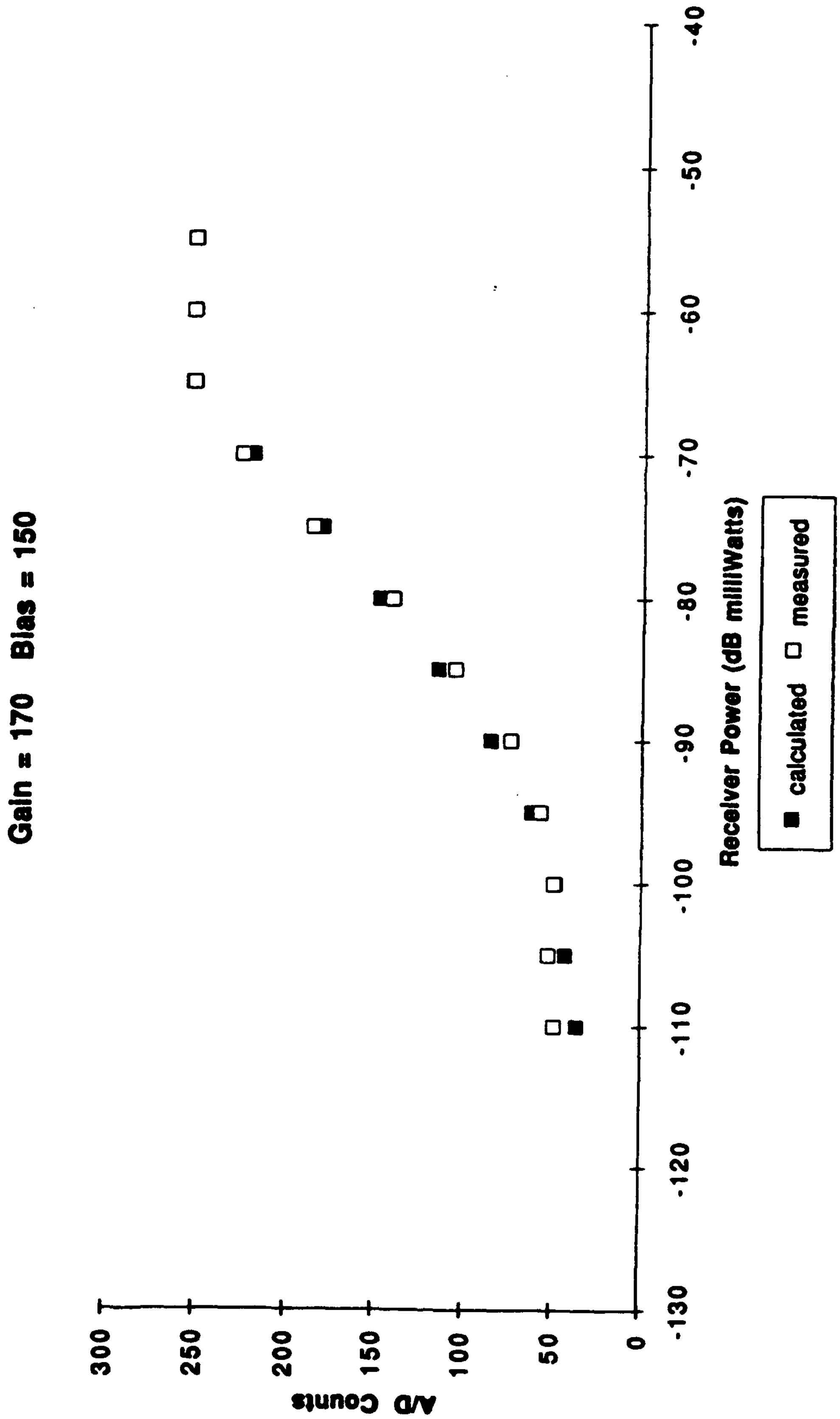

Figure I-20. Data Acquisition System Transfer Function for Gain/Bias = 170/150

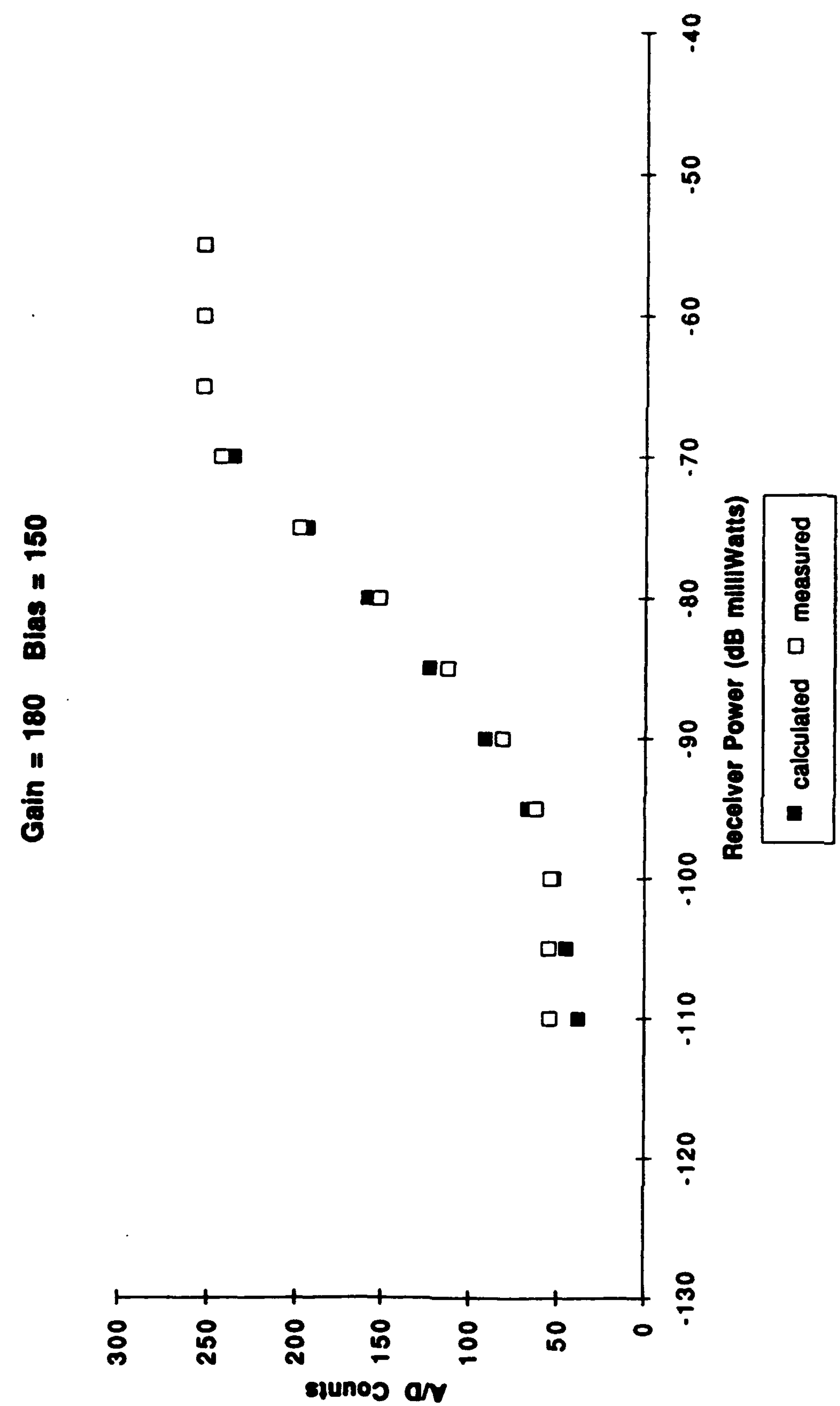

Figure I-21. Data Acquisition System Transfer Function for Gain/Bias = 180/150

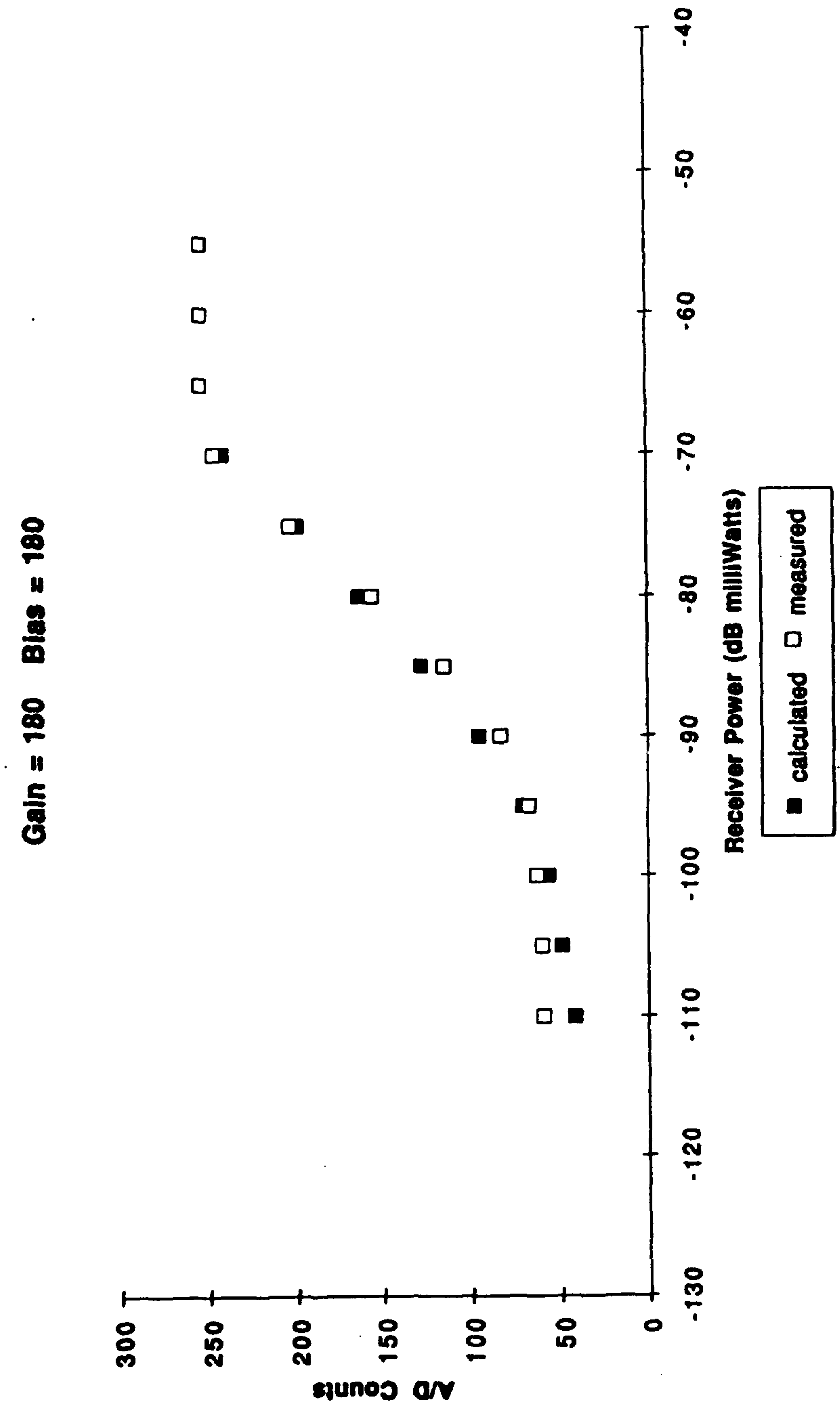

Figure I-22. Data Acquisition System Transfer Function for Gain/Bias = 180/180

APPENDIX J

ANTENNA DATA

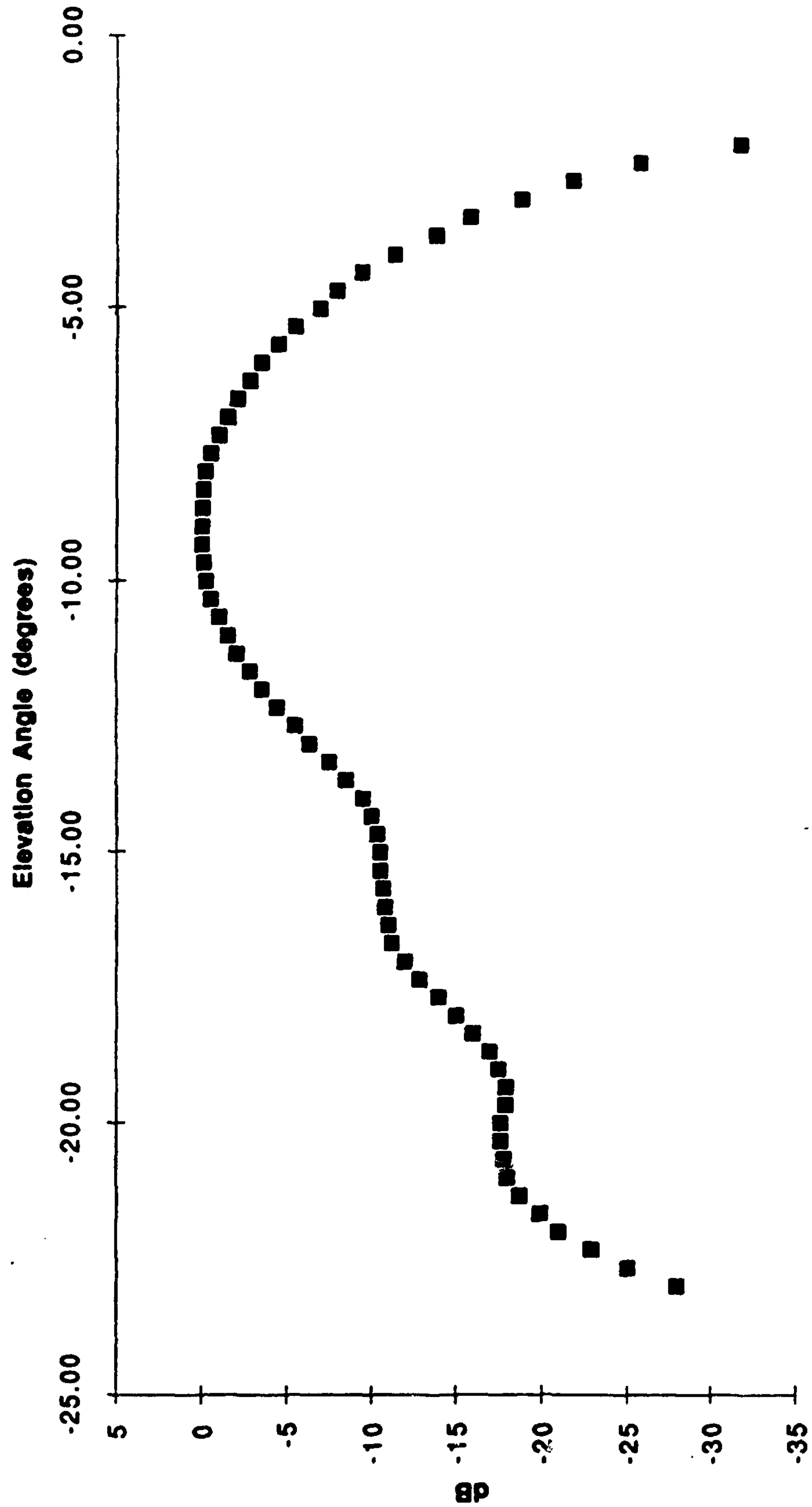

Figure J-1. Measured Elevation Antenna Pattern

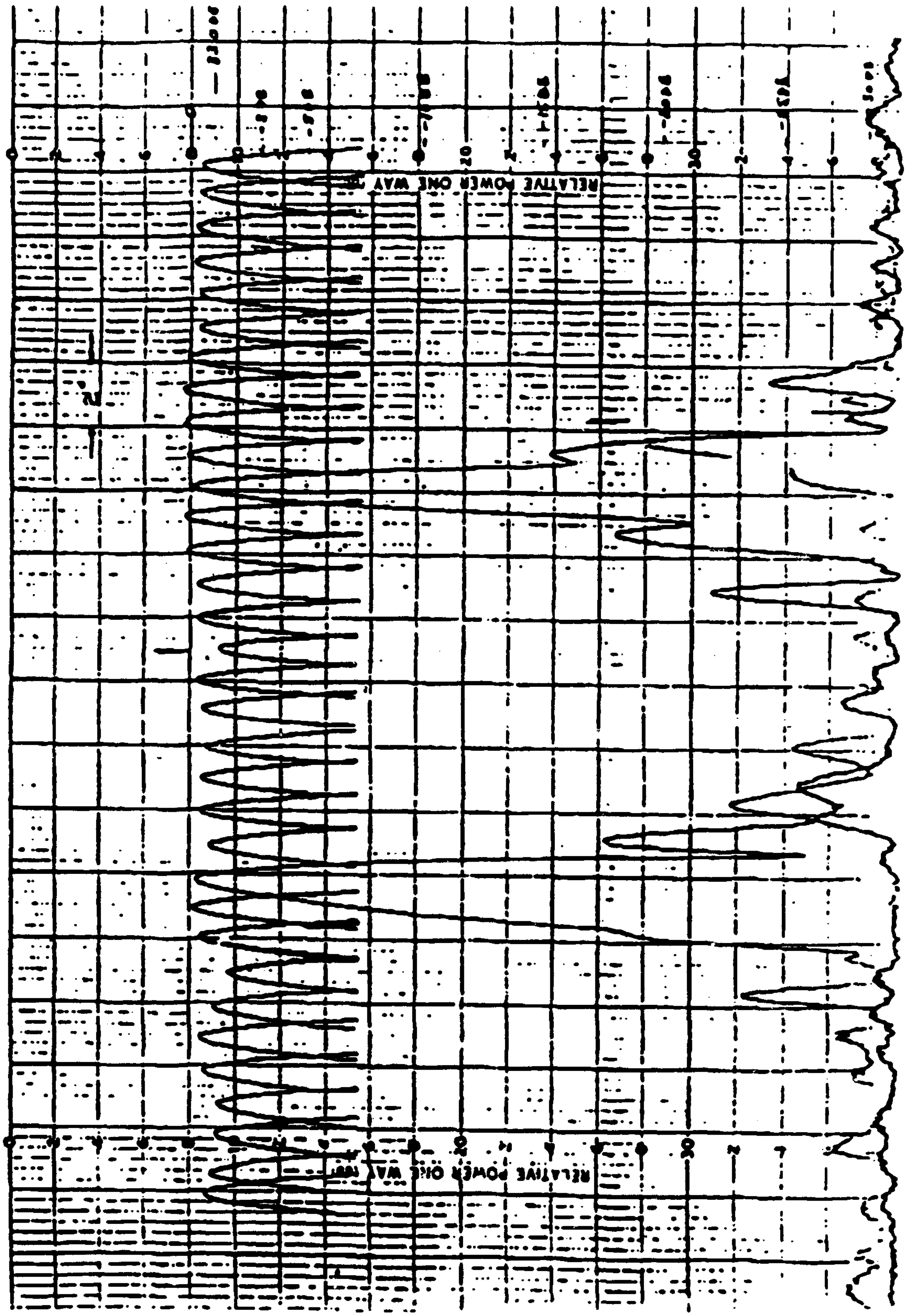

Figure J-2. Measured Azimuth Antenna Pattern

APPENDIX K

PILOT RATINGS AND PERFORMANCE DATA SUMMARY

The pilot ratings and performance data are summarized for all of the flight test evaluations in Table K-1. Table K-2 illustrates the calculations used to estimate the range where the pilots called "runway image". The last two columns are of the most interest as they represent the best estimate of the range from the aircraft position to the runway threshold when the pilot called "runway image". The distance was calculated by noting the runway image callout altitude above the runway and dividing by the tangent of the flight path angle from the aircraft to the glideslope transmitter. One thousand feet was subtracted to account for the fact that the glideslope transmitter is located that far from the threshold. The angle from the aircraft to the glideslope intercept point was estimated by noting the glideslope error when the runway image call was made and adding that value to the glideslope angle (three degrees in all cases). Hence:

$$R_{est} = \frac{h_{baro} - h_{runway}}{\tan(\gamma_{gs} + \gamma_e)} - 1000$$

When available, DME data was used to calculate the runway image call range based on DME. That is shown in the worksheet as column 9. Note that this is a less accurate approximation as the DME only displays in 0.10 nm increments (608 feet) and is inherently noisy. It is calculated primarily as a check on the above estimate.

Table K-1. SVS Flight Test Data Summary

RUN TAG	RUN NO.	PILOT	ARPT	SENSOR	TEST CONDITION	RVR (FT)	CEILING (FT)	PRECIP	RWY IMAGE CALL, RANGE (NM)	RWY IMAGE CALL, ALT (FT)	RWY VISUAL (FT)	W/L APP	W/L FLARE	HQR APP	HQR FLARE	HQR ROLL	QUESTIONNAIRE RESULTS SAFE FOR COM OPS?	QUESTIONNAIRE RESULTS INITIAL ID CORRECT?	XTD (FT)	YTD (FT)	TURB
A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V
1	072092-1A	CA	NTD	FLIR	SIM CAT I	VFR				1300	100								2000	-15	
2	072092-1B	CA	NTD	FLIR	SIM CAT I	VFR				1200	100								800	0	
3	072092-1C	CA	NTD	FLIR	SIM CAT I	VFR				1500	100	2	2	2	2		YES	YES	1800	0	LGT
4	072092-1D	CA	NTD	FLIR	SIM CAT IIIA	VFR				2600	50								2300	-30	LGT
5	072092-1E	CA	NTD	FLIR	SIM CAT IIIA	VFR				2900	50	2	2	2	2	2	YES	YES	1600	0	LGT
6	072092-1F	CA	NTD	FLIR	SIM CAT IIIC	VFR	HQR=2	W/L=2			N/A										XWLGT
7	072092-1G	CA	NTD	35 MMW	SIM CAT IIIA	VFR	Radar offset = 50 ft.		1.60	490	50								1500	30	XWLGT
8	072092-1H	CA	NTD	35 MMW	SIM CAT IIIA	VFR	Radar offset - 80 ft.		1.80	340	50								500	-30	XWLGT
9	072092-1HT	CA	NTD	35 MMW	SIM 600 TO	VFR	HQR = 6				N/A										
10	072092-1I	CA	NTD	35 MMW	SIM CAT IIIC	VFR			1.57	500	0	8	8	7	7	8	NO	YES	900	30	XWLGT
11	072092-2A	MN	NTD	FLIR	SIM CAT IIIA	VFR				3000	50	3	3	3	3		YES	YES	1500	-10	XWLGT
12	072092-2B	MN	NTD	FLIR	SIM CAT IIIC	VFR				2300	0								1300	-30	XWLGT
13	072092-2C	MN	NTD	FLIR	SIM CAT IIIC	VFR				2100	0								1500	-30	XWLGT
14	072092-2D	MN	NTD	FLIR	SIM CAT IIIC	VFR				2300	0	4	4	4	4	3	YES	YES	2000	10	XWLGT
15	072092-2DT	MN	NTD	FLIR	SIM 600 TO	VFR	HQR=3	W/L=2			N/A										
16	072092-3A	MN	NTD	35 MMW	SIM CAT IIIC	VFR			1.71	330	50										XWLGT
17	072092-3AT	MN	NTD	35 MMW	SIM 600 TO	VFR	Image unclear				N/A						NO				
18	072092-3B	MN	NTD	35 MMW	SIM CAT IIIC	VFR			1.43	450	0								1700	30	XWLGT
19	072092-3C	MN	NTD	35 MMW	SIM CAT IIIC	VFR			1.65	330	0	8	8	8	7	5	NO	YES	1500	-30	XWLGT
20	072092-3CT	MN	NTD	35 MMW	SIM 600 TO	VFR	HQR=3	W/L=3			N/A	Using heading and localizer.					NO	Localizer not guaranteed.			XWLGT
21	072292-1A	MN	NTD	35 MMW	SIM CAT IIIA	VFR	Radar offset = 12 ft.		1.41	460	50								GA (too heavy)		LGT
22	072292-1B	MN	NTD	35 MMW	SIM CAT IIIA	VFR			1.35	480	50								2700	0	LGT+
23	072292-1C	MN	NTD	35 MMW	SIM CAT IIIA	VFR			1.29	420	50								3000	0	LGT+
24	072292-1D	MN	NTD	35 MMW	SIM CAT IIIA	VFR			1.45	460	50	3	3	3	3		YES	YES	1000	0	MDT
25	072292-1E	MN	NTD	35 MMW	LOC CAT IIIA	VFR				NONE	50	Theta = 6 deg. missed approach									LGT
26	072292-1F	MN	NTD	35 MMW	LOC CAT IIIA	VFR				NONE	50	Use FLIR to find runway							3000	0	LGT
27	072292-1G	MN	NTD	35 MMW	LOC CAT IIIA	VFR				NONE	50	[illegible] not registered		No returns because of registration problem					2500	0	LGT
28	072292-1H	CA	NTD	35 MMW	SIM CAT IIIA	VFR			1.79	590	50	Moved MMW image up on display							3000	0	LGT+
29	072292-1I	CA	NTD	35 MMW	SIM CAT IIIA	VFR			1.89	600	50	3	2	3	2		YES	YES	1000	0	LGT+
30	072292-1J	CA	NTD	35 MMW	LOC CAT IIIA	VFR			1.79	590	50								1000	0	LGT+
31	072292-1K	CA	NTD	35 MMW	LOC CAT IIIA	VFR			1.86	590	50								1500	0	LGT+
32	072292-1L	CA	NTD	35 MMW	LOC CAT IIIA	VFR			1.83	650	50	3	2	4	2		YES	YES	1300	0	LGT+
33	072392-1A	MN	NTD	35 MMW	LOC CAT IIIA	VFR			Radar not working properly			Disregard data - radar problem this run							3500	0	LGT
34	072392-1B	MN	NTD	35 MMW	LOC CAT IIIA	VFR			1.21	420	50	Simulated surprise fog encounter on runway							no data		LGT
35	072392-1C	MN	NTD	35 MMW	LOC CAT IIIA	VFR			1.78	640	50	3	2	3	2	3 fog	YES	YES	1500	0	LGT
36	072392-2A	CA	NTD	35 MMW	SIM CAT IIIA	VFR			1.69	550	50	On ground - aircraft on runway									NIL
37	072392-2B	CA	NTD	35 MMW	SIM CAT IIIA	VFR			1.57	470	50	Fog bank on runway - stopped on centerline									NIL
38	072392-2C	CA	NTD	35 MMW	SIM CAT IIIA	VFR			1.61	500	50	Simulated HUD failure at touchdown - no problem transferring controls to safety pilot									NIL
39	080492-1A	LO	NTD	35 MMW	SIM CAT I	VFR	Flaps=20 deg. Four lenses			230	100	Disregard data - flaps = 20 deg. pitch attitude +4 deg.							3000+	0	NIL
40	080492-1B	LO	NTD	35 MMW	SIM CAT I	VFR			1.34	480	100	HQR=3 FOR GS; 3 FOR LOC; 4 FOR IAS							1900	10	NIL
41	080492-1C	LO	NTD	35 MMW	SIM CAT I	VFR			1.38	460	100	3	3	3	4		YES	YES	2800	0	NIL
42	080492-1D	LO	NTD	35 MMW	SIM CAT IIIA	VFR			1.37	500	50								3000	10	LGT+

Table K-1. SVS Flight Test Data Summary (Continued)

RUN TAG A	RUN NO. B	PILOT RUN C	ARPT D	SENSOR E	TEST CONDITION F	RVR (FT) G	CEILING (FT) H	PRECIP I	RWY IMAGE RANGE (NM) J	CALL ALT (FT) K	RWY VISUAL (FT) L	W/L APP M	W/L FLARE N	HQR APP O	HQR FLARE P	HQR ROLL Q	QUESTIONNAIRE RESULTS SAFE FOR COM OPS? R	INITIAL ID CORRECT? S	XTD (FT) T	YTD (FT) U	TURB V
43	[illegible]-1D	LO	NTD	35 MMW	SIM CAT [illegible]A	VFR			1.21	460									2300	0	LGT+
44	[illegible]-1E	LO	NTD	35 MMW	SIM CAT [illegible]A	VFR			1.54	500		2.5	2	3	3		YES	YES	1600	20	LGT+
45	[illegible]-1A	CA	[illegible]	35 MMW	CAT [illegible]A	1/16	100	FOG	1.17	380	100	3		3			YES	YES	Missed app.		NIL
46	[illegible]-1B	CA	[illegible]	FLIR	CAT [illegible]A	1/16	100	FOG		NONE	NONE	N/A		N/A			NO	N/A	Missed app.		NIL
47	[illegible]-1C	CA	[illegible]	35 MMW	CAT [illegible]A	3/16	100	FOG	1.18	385	NONE	3		3			YES	YES	Missed app.		NIL
48	[illegible]-1D	CA	[illegible]	FLIR	CAT [illegible]A	1/4	200	FOG		NONE	NONE						NO	N/A	Missed app.		NIL
49	[illegible]-1E	CA	[illegible]	35 MMW	CAT [illegible]A	5/8	200	FOG	1.28	430	NONE	3		3			YES	YES	Missed app.		NIL
50	[illegible]-1F	CA	[illegible]	FLIR	CAT [illegible]A	1	300	FOG		NONE	NONE	N/A		N/A			NO	N/A	Missed app.		NIL
51	[illegible]-1G	CA	[illegible]	35 MMW	CAT [illegible]A	1	300	FOG	1.19	410	200	3	2	3	2		YES	YES	4000	0	NIL
52	081192-1A	LO	[illegible]	35 MMW	CAT [illegible]A	1/8	100	FOG	1.29	380	NONE	3	3	3	3		YES	YES	Missed App.		NIL
53	081192-1B	LO	[illegible]	FLIR	CAT [illegible]A	1/8	100	FOG		210	NONE	N/A		N/A			NO	N/A	4000	15	NIL
54	081192-1C	LO	[illegible]	35 MMW	CAT [illegible]A		100	FOG	0.94	300	NONE	3	3	3	2		YES	YES	5000	15	NIL
55	081192-1D	LO	[illegible]	FLIR	CAT [illegible]A	3/16	100	FOG		NONE	NONE	N/A		N/A			NO	N/A	Missed App.		NIL
56	081192-1E	LO	[illegible]	35 MMW	CAT [illegible]A	3/16	100	FOG	1.35	430	NONE	3		3			YES	YES	Missed App.		NIL
57	081192-1F	LO	[illegible]	FLIR	CAT [illegible]A	1/2	100	FOG		NONE	200	N/A		N/A			NO	N/A	Missed App.		NIL
58	[illegible]-1A	MN	[illegible]	35 MMW	CAT [illegible]A	1/8	100	FOG	1.10	350	NONE	2		3			YES	YES	Missed App.		NIL
59	[illegible]-1B	MN	[illegible]	FLIR	CAT [illegible]A	1/8	100	FOG		NONE	NONE	N/A		N/A			YES (Using Symbology)		Missed App.		NIL
60	[illegible]-1C	MN	[illegible]	35 MMW	CAT [illegible]A	1/8	100	FOG	1.08	350	NONE	2		2			YES	YES	Missed App.		NIL
61	[illegible]-1D	MN	[illegible]	FLIR	CAT [illegible]A	1/8	100	FOG		NONE	NONE	N/A		N/A			YES (Using Symbology)		Missed App.		NIL
62	[illegible]-1E	MN	[illegible]	35 MMW	CAT [illegible]A	1/8	100	FOG	1.45	460	NONE	2		2			YES	YES	Missed App.		NIL
63	[illegible]-1F	MN	[illegible]	FLIR	CAT [illegible]A	1/8	100	FOG		NONE	NONE	N/A		N/A			YES (Using Symbology)		Missed App.		NIL
64	[illegible]-2B	LO	NTD	35 MMW	SIM CAT [illegible]A	VFR			1.52	490	50								3500	25	XW/LGT
65	[illegible]-2C	LO	NTD	35 MMW	SIM CAT [illegible]C	VFR			1.59	510	0								2000	10	XW/LGT
66	[illegible]-2D	LO	NTD	35 MMW	SIM CAT [illegible]C	VFR	[illegible] (cloud)		1.79	570	0	3	3	3	3	9	YES	YES	2500	10	XW/LGT
67	[illegible]-3A	LO	NTD	35 MMW	LOC CAT [illegible]A	VFR			1.81	710	50								3000	10	XW/LGT
68	[illegible]-3B	LO	NTD	35 MMW	LOC CAT [illegible]A	VFR			1.81	750	50								3000	10	XW/LGT
69	[illegible]-3C	LO	NTD	35 MMW	LOC CAT [illegible]A	VFR			1.76	670	50	3	3	3	3		YES	YES	Go around		XW/LGT
70	[illegible]-1A	MN	NTD	FLIR	[illegible] CAT [illegible]A	VFR	Radar Cal		1.43	440	50	3		5.5			NO	YES	1250		NIL
71	[illegible]-1B	MN	NTD	FLIR	[illegible] CAT [illegible]A	VFR	Radar Cal		1.96	630	50	3		3			NO	YES	1200		NIL
72	[illegible]-1C	MN	NTD	35 MMW	[illegible] CAT [illegible]A	VFR	Radar Cal		1.46	480	50	3		5.5			NO	YES	1400		NIL
73	[illegible]-1D	MN	NTD	35 MMW	[illegible] CAT [illegible]A	VFR	Radar Cal		1.28	420	50	3		3			NO	YES	1250		LGT
74	081892-1A	CA	LAX	35 MMW	SIM CAT I	3	400	FOG	1.08	350	200						YES	YES	1800	10	NIL
75	081892-1B	CA	LAX	35 MMW	RADAR CAL	3	100	FOG	0.95	310	NONE						YES	YES	Missed Appro		NIL
76	081892-1C	MN	LAX	35 MMW	RADAR CAL	3	300	FOG	1.26	400	75	3		3			YES	YES	1500		NIL
77	081892-1D	MN	SAN	35 MMW	SIM CAT IIIA	VFR				NONE	NONE	10		8			NO	N/A	Missed Appro		NIL
78	081892-1E	MN	SAN	35 MMW	RADAR CAL	VFR			0.94	300	NONE	3		3			?	?	Low Approach		NIL
79	081892-1F	CA	SAN	35 MMW	RADAR CAL	VFR				NONE	NONE	10		8			NO	N/A	Low Approach		NIL
80	081892-1G	CA	CRQ	35 MMW	SIM CAT I	1.25	400	FOG	1.38	440	200	3		3			YES	YES	1500	0	NIL
81	081892-1H	CA	CRQ	35 MMW	RADAR CAL	VFR			1.46	490	50	4		3			YES	YES	1200	-3	NIL
82	081892-1I	MN	CRQ	35 MMW	RADAR CAL	VFR			1.13	360	50	3		3			YES	YES	1500	0	NIL
83	081892-2A	MN	NTD	35 MMW	SIM CAT IIIA	VFR			1.26	400	50						YES	YES	Low Approach		NIL
84	081892-2B	MN	NTD	35 MMW	RADAR CAL	VFR			1.42	450	50	3		3			YES	YES	1800	0	NIL
85	081892-2C	MN	NTD	35 MMW	Runway intrusio	VFR	Truck not noticed		1.38	450	50	3		3			YES	YES	1600	0	NIL

Table K-1. SVS Flight Test Data Summary (Continued)

RUN TAG	RUN NO.	PILOT	ARPT	SENSOR	TEST CONDITION	RVR (FT)	CEILING (FT)	PRECIP	IMAGE CALL RANGE (NM)	IMAGE CALL ALT (FT)	RWY VISUAL (FT)	W/L APP	W/L FLARE	HQR APP	HQR FLARE	HQR ROLL	QUESTIONNAIRE SAFE FOR COM OPS?	RESULTS INITIAL ID CORRECT?	X(1) (FT)	Y(1) (FT)	TURB
A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V
86	[illegible]	MN	[illegible]	35 MMW	SIM CAT IIIA	VFR	rwy spotted			No Call	NONE	3		3			YES	YES	Missed App		NIL
87	[illegible]	MN	[illegible]	35 MMW	SIM CAT IIIA	VFR	rwy not noticed		1.48	430	50	3		3			YES	YES	1300	0	NIL
88	[illegible]	MN	[illegible]	35 MMW	SIM CAT IIIA	VFR	rwy spotted		1.64	320	NONE	3		3			YES	YES	Missed App		NIL
89	[illegible]	MN	[illegible]	35 MMW	SIM CAT IIIA	VFR	rwy spotted		1.31	400	50	3		3			YES	YES	1700	0	NIL
90	[illegible]	MN	[illegible]	35 MMW	SIM 00 TO	VFR	rwy not noticed			170											NIL
91	[illegible]	MN	[illegible]	35 MMW	SIM 00 TO	VFR	rwy spotted			170											NIL
92	[illegible]	MN	[illegible]	35 MMW	SIM CAT I	VFR			1.24	300	200	3		3			YES	YES	1200	0	LO[illegible] •
93	[illegible]	MN	[illegible]	35 MMW	SIM CAT IIIA	VFR			1.60	310	50	3		3			YES	YES	1500	0	LO[illegible] •
94	[illegible]	MN	[illegible]	35 MMW	SIM CAT IIIA	VFR			1.62	310	50	3		3			YES	YES	2000	-10	LO[illegible] •
95	[illegible]	MN	[illegible]	35 MMW	SIM CAT IIIA	VFR			0.79	250	50	3		3			YES	YES	1800	0	LO[illegible] •
96	[illegible]	MN	[illegible]	35 MMW	SIM CAT II	VFR			1.32	420	100	3		3			YES	YES	N/A		LO[illegible] •
97	[illegible]	MN	[illegible]	35 MMW	SIM CAT IIIA	VFR			1.31	400	50	3		3			YES	YES	N/A		LO[illegible] •
98	[illegible]	MN	[illegible]	35 MMW	SIM CAT IIIA	VFR	No data			N/A	50	N/A		N/A			YES	YES	N/A		LO[illegible] •
99	[illegible]	MN	[illegible]	35 MMW	SIM CAT IIIA	4	500	FOG	0.99	310	50	3		3			YES	YES	1600	0	NIL
100	[illegible]	MN	[illegible]	35 MMW	SIM CAT IIIA	VFR			0.83	280	50	3		3			YES	YES	?	0	NIL
101	[illegible]	MN	[illegible]	35 MMW	SIM CAT IIIA	VFR			0.90	190	50	3		3			YES	YES	1500	3	NIL
102	[illegible]	CA	[illegible]	35 MMW	CAT I	1/8	100	FOG	1.49	430	50	3		3			YES	YES	2000	10	NIL
103	[illegible]	CA	[illegible]	35 MMW	CAT I	1/8	100	FOG	1.31	450	NONE	3		3			YES	YES	Missed App		NIL
104	[illegible]	CA	[illegible]	35 MMW	CAT I	1/8	100	FOG	1.20	400	NONE	3		3			YES	YES	Missed App		NIL
105	[illegible]	LO	[illegible]	35 MMW	CAT I	1/8	100	FOG	0.13	160	60	3		3			YES	YES	1700	10	NIL
106	[illegible]	LO	[illegible]	35 MMW	CAT I	1/8	100	FOG	1.36	360	NONE	Radar failed at 80 ft					YES	YES	Missed App		NIL
107	[illegible]	CA	[illegible]	35 MMW	CAT I	1/8	100	FOG	1.70	340	110										
108	[illegible]	LO	ACV	35 MMW	SIM CAT IIIA	[illegible]	500	FOG	1.13	180											
109	[illegible]	CA	ACV	35 MMW	SIM CAT IIIA	[illegible]	500	FOG	1.67	330											
110	[illegible]	CA	ACV	35 MMW	SIM CAT IIIA	[illegible]	500	FOG	1.44	460											
111	[illegible]	CA	ACV	35 MMW	SIM CAT IIIA	[illegible]	500	FOG	1.61	330											
112	[illegible]	CA	ACV	35 MMW	SIM CAT IIIA	[illegible]	500	FOG	1.73	350											
113	[illegible]	CA	ACV	35 MMW	CAT IIIA	800	[illegible]	FOG	0.13	290	50	2	3	3	3		YES	YES	2000+	0	NIL
114	[illegible]	CA	ACV	35 MMW	CAT IIIA	1000	[illegible]	FOG	0.17	310	60	3	3	2.5	3		YES	YES	1200	-3	NIL
115	[illegible]	LO	ACV	35 MMW	CAT IIIA	700	[illegible]	FOG	0.91	360	70	Off to right					NO	YES			NIL
116	[illegible]	LO	ACV	35 MMW	CAT IIIA	700	[illegible]	FOG	1.42	450	NONE	3		3	Left shield up		NO	YES			NIL
117	[illegible]	LO	ACV	35 MMW	CAT IIIA	1000	[illegible]	FOG	1.63	330	70	4	2	4	2		NO	YES	1200	10	NIL
118	[illegible]	LO	ACV	35 MMW	CAT IIIA	1000	[illegible]	FOG	1.70	340	80	4	2	3	2		NO	YES	1500	10	NIL
119	[illegible]	CA	ACV	35 MMW	CAT I	1200	[illegible]	FOG	1.61	290	75	2	3	3	3		YES	NO	900	0	NIL
120	[illegible]	CA	ACV	35 MMW	CAT I	4500	[illegible]	FOG	1.54	460	120	3	2	3	2		YES	YES	700	10	NIL
121	[illegible]	LO	ACV	35 MMW	SIM CAT IIIA	>6000	200	FOG	0.11	180	NONE	Inadvertently left shield on HUD									NIL
122	[illegible]	LO	ACV	35 MMW	CAT I	>6000	200	FOG	1.63	330	200	2.5	2.5	3	2.5		YES	YES	1200	10	NIL
123	[illegible]	LO	[illegible]	35 MMW	CAT I	1/8	100	FOG	0.16	275	100	10		10			NO	NO	Missed App		NIL
124	[illegible]	LO	[illegible]	35 MMW	CAT I	1/8	100	FOG	0.13	290	100	10		10			NO	NO	Missed App		NIL
125	[illegible]	LO	[illegible]	35 MMW	CAT I	1/8	100	FOG	0.11	225	100	10		10			NO	NO	Missed App		NIL
126	092592-1A	MN	[illegible]	35 MMW	RAIN DATA	7	1100	R-W		No call		Workload very high due to winds and turbulence							Not relevant		XW/MDT
127	[illegible]	MN	[illegible]	35 MMW	RAIN DATA	7	1100	R-W	0.18	345	600	Workload very high due to winds and turbulence							Not relevant		XW/MDT
128	[illegible]	MN	NHK	35 MMW	RAIN DATA	4	700	R-F		No image	700	Workload very high due to winds and turbulence							Not relevant		XW/MDT
129	092592-1D	MN	NHK	35 MMW	RAIN DATA	4	700	R-F	0.15	240	470	Poor image quality - large crosswind					NO	-	Not relevant		XW/MDT

Table K-1. SVS Flight Test Data Summary (Continued)

RUN TAG A	RUN NO. B	PILOT C	ARPT D	SENSOR E	TEST CONDITION F	RVR (FT) G	CEILING (FT) H	PRECIP I	RWY IMAGE RANGE (NM) J	CALL ALT (FT) K	RWY VISUAL (FT) L	W/L APP M	W/L FLARE N	HQR APP O	HQR FLARE P	HQR ROLL Q	QUESTIONNAIRE SAFE FOR COM OPS? R	RESULTS INITIAL (E) CORRECT? S	XTD (FT) T	YTD (FT) U	TURB V
30	[illegible]	[illegible]	MV	35 MMW	RAIN DATA	2	300	[illegible]	0.45	140	750	Poor image quality - WX radar red on level					NO	-	Not relevant		XW/MDT
31	[illegible]	[illegible]	MV	FLIR	RAIN DATA	2	300	[illegible]		NONE	300	Radar blanking up (SVS shutdown) - no image on MMW							Not relevant		XW/MDT
32	[illegible]	[illegible]	ACY	FLIR	RAIN DATA	2	1200	[illegible]		NONE	320	Strong XW - flight director not visible on HUD							Not relevant		XW/MDT
33	[illegible]	[illegible]	ACY	35 MMW	RAIN DATA	2	300	[illegible]		NONE	750	Strong XW - flight director not visible on HUD - WX radar red and purple							Not relevant		XW/MDT
34	[illegible]	[illegible]	ACY	35 MMW	RAIN DATA	2	300	[illegible]	0.30	241											
35	[illegible]	[illegible]	[illegible]	35 MMW	CAT I	[illegible]	100	[illegible]	0.69	200	100	(Approach lights in sight at 200 ft call)							1500	0	LGT
36	[illegible]	[illegible]	[illegible]	35 MMW	CAT I	[illegible]	100	[illegible]	1.16	170	100	3	3	3	3		YES	YES	1700	0	LGT
37	[illegible]	[illegible]	[illegible]	35 MMW	CAT I	[illegible]	100	[illegible]	1.14	170	100	3	3	3	3		YES	YES	1200	0	LGT
38	[illegible]	[illegible]	[illegible]	FLIR	CAT I	[illegible]	100	[illegible]		NONE	100	N/A (No image)					YES	YES			LGT
39	[illegible]	[illegible]	[illegible]	FLIR	CAT I	[illegible]	100	[illegible]	1.16	170	100	4	4	3	3		YES	YES	1200	0	XW/LGT
40	[illegible]	[illegible]	[illegible]	35 MMW	CAT I	[illegible]	100	[illegible]	1.16	170	100	3	3	3	3	3	YES	YES	1500	0	LGT
41	[illegible]	[illegible]	[illegible]	35 MMW	CAT I	[illegible]	100	[illegible]	1.31	420	100	3	3	3	3	3	YES	YES	1500	0	LGT
42	[illegible]	[illegible]	[illegible]	35 MMW	CAT I	[illegible]	100	[illegible]	1.26	400	100	3	3	3	3	3	YES	YES	1200	0	LGT
43A	[illegible]	[illegible]	ACY	35 MMW	DOC DRY RWY	VFR			1.03	400							(Low Approaches)				LGT
43B	[illegible]	[illegible]	MV	35 MMW	DOC DRY RWY	VFR			1.39	400											
43C	[illegible]	[illegible]	[illegible]	35 MMW	DOC DRY RWY	VFR			1.34	500											
44	[illegible]	[illegible]	[illegible]	35 MMW	CAT IIIA	0	W/X	[illegible]	1.16	310	NONE	(Restricted to Cat I at this airport)					YES	YES	Missed App		NIL
45	[illegible]	[illegible]	[illegible]	35 MMW	CAT IIIA	0	W/X	[illegible]	1.14	330	NONE						YES	YES	Missed App		NIL
46	[illegible]	[illegible]	[illegible]	35 MMW	CAT IIIA	0	W/X	[illegible]	0.90	330	NONE	3		3			YES	YES	Missed App		NIL
47	[illegible]	[illegible]	[illegible]	35 MMW	CAT IIIA	0	W/X	[illegible]	1.04	320	NONE	3		3			YES	YES	Missed App		NIL
48	[illegible]	[illegible]	[illegible]	35 MMW	CAT IIIA	0	W/X	[illegible]	1.04	330	NONE	3		3			YES	YES	Missed App		NIL
49	[illegible]	[illegible]	[illegible]	35 MMW	CAT IIIA	1/16	W/X	[illegible]	1.31	420	NONE	3		3			YES	YES	Missed App		NIL
SUITABILITY RUNS FOR LEAR 94 GHZ RADAR																					
150	[illegible]	CA	[illegible]	94 MMW	Suitability	VFR			0.50	170		Image too late		(Need image above 200 ft to rate)							NIL
151	[illegible]	CA	[illegible]	94 MMW	Suitability	VFR			0.51	150		Image too late		(Need image above 200 ft to rate)							LGT
152	[illegible]	CA	[illegible]	94 MMW	Suitability	VFR			0.50	150		Image too late		(Need image above 200 ft to rate)							LGT
153	[illegible]	[illegible]	[illegible]	94 MMW	Suitability	VFR			0.48	160		Image too late		(Need image above 200 ft to rate)							LGT
154	[illegible]	[illegible]	[illegible]	94 MMW	Suitability	VFR			0.40	130		Image too late		(Need image above 200 ft to rate)							LGT
155	[illegible]	[illegible]	VNY	94 MMW	Suitability	VFR			0.52	190		Image too late		(Need image above 200 ft to rate)							LGT
156	[illegible]	[illegible]	[illegible]	94 MMW	Suitability	VFR			0.50	200		Image too late		(Need image above 200 ft to rate)							LGT
157	[illegible]	[illegible]	[illegible]	94 MMW	Suitability	VFR			0.53	170		Image too late		(Need image above 200 ft to rate)							LGT
158	[illegible]	[illegible]	[illegible]	94 MMW	Suitability	VFR			0.44	40		Image too late		(Need image above 200 ft to rate)							LGT
159	[illegible]	[illegible]	[illegible]	94 MMW	Suitability	VFR			0.41	170		Image too late		(Need image above 200 ft to rate)							LGT
160	[illegible]	[illegible]	VNY	94 MMW	Suitability	VFR			0.53	120		Image degraded rapidly below 120 feet. Lost flare cue in clutter									LGT

Table K-1. SVS Flight Test Data Summary (Continued)

RUN TAG A	RUN NO. B	PILOT C	ARPT D	SENSOR E	TEST CONDITION F	RVR (FT) G	CEILING (FT) H	PRECIP I	RWY IMAGE CALL RANGE (NM) J	RWY IMAGE CALL ALT (FT) K	RWY VISUAL (FT) L	W/L APP M	W/L FLARE N	HQR APP O	HQR FLARE P	HQR ROLL Q	QUESTIONNAIRE RESULTS SAFE FOR COM OPS? R	QUESTIONNAIRE RESULTS INITIAL ID CORRECT? S	XTD (FT) T	YTD (FT) U	TURB V
161	112092-1A	CA	NTD	35 MMW	SIM CAT IIIA	VFR	VFR	NONE	1.51	470											NIL
162	112092-1B	CA	PUB	35 MMW	Snow on rwy	3/4	600	S-F		No Image	600	No usable image to rate					NO	N/A	Low App		NIL
163	112092-1C	CA	PUB	35 MMW	Snow on rwy	3/4	600	S-F		No Image	200	No usable image to rate					NO	N/A	Low App		NIL
164	112092-1D	MN	PUB	35 MMW	Snow on rwy	3/4	600	S-F		No Image	300	No usable image to rate					NO	N/A	Low App		NIL
165	112092-1E	MN	PUB	35 MMW	Snow on rwy	3/4	600	S-F		No Image	330	No usable image to rate					NO	N/A	Snow on runway		
166	112192-1A	MN	PUB	35 MMW	Plowed Rwy	3	1600	NONE	0.42	130	1,500	No usable image to rate					NO	N/A			NIL
167	112192-1B	MN	PUB	35 MMW	Plowed Rwy	3	1600	NONE	0.23	70	2,000	No usable image to rate					NO	N/A	Low App		NIL
168	112192-1C	CA	COS	35 MMW	Plowed Rwy	10	4300	NONE	0.50	150	1,400	No usable image to rate					NO	N/A			NIL
169	112192-1D	CA	COS	35 MMW	Plowed Rwy	10	4500	NONE		No Image	1,400	No usable image to rate					NO	N/A	Low App		NIL
170	112792-1A	MN	NTD	35 MMW	No Navaid	VFR	Simulated no Navaid		1.40	160		3		3			YES	YES	Low App		NIL
171	112792-1B	MN	NTD	35 MMW	No Navaid	VFR	approaches to 50 ft DH		1.70	700		10		10	Very low		NO	YES	Low App		NIL
172	112792-1C	MN	NTD	35 MMW	No Navaid	VFR			1.30	370		3		3			YES	YES	Low App		NIL
173	112792-1D	CA	NTD	35 MMW	No Navaid	VFR			1.70	400		3		3			YES	YES	Low App		NIL
174	112792-1E	CA	NTD	35 MMW	No Navaid	VFR			1.70	340		4		4			YES	YES	Low App		NIL
175	112792-1F	CA	NTD	35 MMW	No Navaid	VFR	lateral 1.5 dot offset		1.70	630		7		7			NO	YES	Low App		NIL
176	112792-1G	CA	VNY	35 MMW	No Navaid	VFR			1.42	450		4		3			YES	YES	1500	0	NIL

NOTES:

TURBULENCE CODE

- NIL Turbulence was not enough to affect pilot workload (not mentioned in comments)
- LOT Enough turbulence to cause pilot to comment on it - judged to have some effect on workload
- MDT Judged to have a significant impact on pilot workload from the commentary
- XW Crosswind with enough effect to have an impact on pilot workload based on commentary

RWY IMAGE Altitude where pilot called "Runway Image"
RWY VISUAL Altitude where pilot made "Visual Land" call (i.e., pilot could see actual runway)

Table K-2. Runway Image Callout Range and Altitude - 35 GHz MMw Radar

RUN TAG	RUN NUMBER	AIRPORT	PILOT	WX	RWY IMAGE CALLOUT ALTITUDE (FT)	DME RANGE TO XMITTER (NM)	DME XMITTER TO THRESHHOLD DISTANCE (FT)	DME RANGE TO THRESHHOLD (APPROX) (FT)	GLIDESLOPE ERROR AT RUNWAY IMAGE CALL DOTS	RANGE TO THRESHHOLD BASED ON ALTITUDE (FT)	RANGE TO THRESHHOLD BASED ON ALTITUDE (NM)
1	072092-1A	NTD	CA	NONE	FLIR		12,150				
2	072092-1B	NTD	CA	NONE	FLIR		12,150				
3	072092-1C	NTD	CA	NONE	FLIR		12,150				
4	072092-1D	NTD	CA	NONE	FLIR		12,150				
5	072092-1E	NTD	CA	NONE	FLIR		12,150				
6	072092-1F	NTD	CA	NONE	FLIR		12,150				
7	072092-1G	NTD	CA	NONE	490	3.60	12,150	9,724	-0.30	9,703	1.60
8	072092-1H	NTD	CA	NONE	560	3.90	12,150	11,546	-0.20	10,956	1.80
9	072092-1IT	NTD	CA	NONE	0		12,150				
10	072092-1I	NTD	CA	NONE	500	3.70	12,150	10,331	0.00	9,554	1.57
11	072092-2A	NTD	MN	NONE	FLIR		12,150				
12	072092-2B	NTD	MN	NONE	FLIR		12,150				
13	072092-2C	NTD	MN	NONE	FLIR		12,150				
14	072092-2D	NTD	MN	NONE	FLIR		12,150				
15	072092-2ET	NTD	MN	NONE	T/O		12,150				
16	072092-2E	NTD	MN	NONE	530	3.70	12,150	10,331	-0.20	10,369	1.71
17	072092-2FT	NTD	MN	NONE	T/O		12,150				
18	072092-2F	NTD	MN	NONE	450	3.50	12,150	9,116	0.00	8,599	1.42
19	072092-2G	NTD	MN	NONE	530	3.70	12,150	10,331	0.10	10,011	1.65
20	072092-2HT	NTD	MN	NONE	T/O		12,150				
21	072292-1A	NTD	MN	NONE	460	3.50	12,150	9,116	0.20	8,590	1.41
22	072292-1B	NTD	MN	NONE	480	3.60	12,150	9,724	-0.20	9,391	1.55
23	072292-1C	NTD	MN	NONE	420	3.40	12,150	8,508	0.20	7,843	1.29
24	072292-1D	NTD	MN	NONE	460	3.50	12,150	9,116	0.00	8,790	1.45
25	072292-1E	NTD	MN	NONE	NONE		12,150				
26	072292-1F	NTD	MN	NONE	NONE		12,150				
27	072292-1G	NTD	MN	NONE	NONE		12,150				
28	072292-1H	NTD	CA	NONE	590	3.70	12,150	10,331	0.30	10,893	1.79
29	072292-1I	NTD	CA	NONE	600	3.90	12,150	11,546	0.00	11,465	1.89
30	072292-1J	NTD	CA	NONE	590	3.90	12,150	11,546	0.30	10,893	1.79
31	072292-1K	NTD	CA	NONE	590	3.90	12,150	11,546	0.00	11,274	1.86
32	072292-1L	NTD	CA	NONE	650	4.00	12,150	12,154	0.90	11,242	1.85
33	072392-1A	NTD	MN	NONE	Radar N. G.		12,150				
34	072392-1B	NTD	MN	NONE	420	3.50	12,150	9,116	0.80	7,341	1.21
35	072392-1C	NTD	MN	NONE	640	3.80	12,150	10,939	1.10	10,840	1.78
36	072392-2A	NTD	CA	NONE	550	3.70	12,150	10,331	0.20	10,270	1.69
37	072392-2B	NTD	CA	NONE	470	3.50	12,150	9,116	-0.50	9,537	1.57
38	072392–2C	NTD	CA	NONE	500	3.70	12,150	10,331	-0.20	9,782	1.61
39	080492-1A	NTD	LO	NONE	N/A	2.80	12,150	4,863	0.00	4,395	
40	080492-1B	NTD	LO	NONE	480	3.40	12,150	8,508	1.10	8,130	1.34
41	080492-1C	NTD	LO	NONE	460	3.50	12,150	9,116	0.40	8,398	1.38
42	080492-1D	NTD	LO	NONE	500	3.70	12,150	10,331	0.00	9,554	1.57

Table K-2. Runway Image Callout Range and Altitude - 35 GHz MMw Radar (Continued)

RUN TAG	RUN NUMBER	AIRPORT	PILOT	WX	RUNWAY IMAGE CALLOUT ALTITUDE (FT)	DME RANGE TO XMITTER (NM)	DME XMITTER TO THRESHHOLD DISTANCE (FT)	DME RANGE TO THRESHHOLD (APPROX) (FT)	DME ERROR AT RUNWAY IMAGE CALL DOTS	DME THRESHHOLD BASED ON ALTITUDE (FT)	DME THRESHHOLD BASED ON ALTITUDE (NM)
43	080492-1E	NTD	LO	NONE	460	3.60	12,150	9,724	0.20	8,590	1.41
44	080492-1F	NTD	LO	NONE	500	3.70	12,150	10,331	0.20	9,337	1.54
45	080892-1A	VBG	CA	FOG	380	2.30	6,076	7,899	0.20	7,096	1.17
46	080892-1B	VBG	CA	FOG	FLIR		6,076				
47	080892-1C	VBG	CA	FOG	385	2.30	6,076	7,899	0.20	7,189	1.18
48	080892-1D	VBG	CA	FOG	FLIR		6,076				
49	080892-1E	VBG	CA	FOG	420	2.40	6,076	8,506	0.30	7,755	1.28
50	080892-1F	VBG	CA	FOG	FLIR		6,076				
51	080892-1G	VBG	CA	FOG	410	2.40	6,076	8,506	0.70	7,244	1.19
52	081192-1A	VBG	LO	FOG	380	2.50	6,076	9,114	0.00	7,261	1.20
53	081192-1B	VBG	LO	FOG	FLIR		6,076				
54	081192-1C	VBG	LO	FOG	300	2.10	6,076	6,684	0.00	5,733	0.94
55	081192-1D	VBG	LO	FOG	FLIR		6,076				
56	081192-1E	VBG	LO	FOG	430	DME INOP	6,076		0.00	8,217	1.35
57	081192-1F	VBG	LO	FOG	FLIR		6,076				
58	081392-1A	VBG	MN	FOG	350	2.20	6,076	7,291	0.00	6,688	1.10
59	081392-1B	VBG	MN	FOG	FLIR		6,076				
60	081392-1C	VBG	MN	FOG	350	2.20	6,076	7,291	0.20	6,336	1.08
61	081392-1D	VBG	MN	FOG	FLIR		6,076				
62	081392-1E	VBG	MN	FOG	460	2.40	6,076	8,506	0.00	8,790	1.45
63	081392-1F	VBG	MN	FOG	FLIR		6,076				
64	081392-2A	NTD	LO	NONE	490	3.60	12,150	9,724	0.10	9,255	1.52
65	081392-2B	NTD	LO	NONE	510	3.60	12,150	9,724	0.10	9,633	1.59
66	081392-2C	NTD	LO	NONE	570	3.80	12,150	10,939	0.00	10,892	1.79
67	081392-2D	NTD	LO	NONE	710	3.90	12,150	11,546	2.00	11,003	1.81
68	081392-2E	NTD	LO	NONE	750	3.90	12,150	11,546	2.00	11,623	1.91
69	081392-2F	NTD	LO	NONE	670	3.80	12,150	10,939	1.70	10,686	1.76
70	081792-1A	NTD	MN	NONE	HDDFLIR	3.50	12,150	9,116	0.10	8,689	1.43
71	081792-1B	NTD	MN	NONE	HDDFLIR	4.00	12,150	12,154	0.10	11,900	1.96
72	081792-1C	NTD	MN	NONE	480	3.60	12,150	9,724	0.30	8,862	1.46
73	081792-1D	NTD	MN	NONE	420	3.40	12,150	8,508	0.30	7,755	1.28
74	081892-1A	LAX	CA	FOG	350	3.20	12,150	7,293	0.20	6,536	1.08
75	081892-1B	LAX	CA	FOG	310	2.90	12,150	5,470	0.20	5,789	0.95
76	081892-1C	LAX	MN	FOG	400	3.40	12,150	8,508	0.00	7,643	1.26
77	081892-1D	SAN	MN	NONE	NONE	NO DME	N/A				
78	081892-1E	SAN	MN	NONE	300	NO DME	N/A			5,733	0.94
79	081892-1F	SAN	CA	NONE	NONE	NO DME	N/A				
80	081892-1G	CRQ	CA	FOG	440	NO DME	N/A		0.00	8,408	1.38
81	081892-1H	CRQ	CA	NONE	490	NO DME	N/A		0.50	8,848	1.46
82	081892-1I	CRQ	MN	NONE	360	NO DME	N/A		0.00	6,879	1.13
83	081892-2A	NTD	MN	NONE	400	NO VIDEO	N/A		0.00	7,643	1.26
84	081892-2B	NTD	MN	NONE	450	3.60	12,150	9,724	0.00	8,599	1.42
85	081892-2C	NTD	MN	NONE	450	3.50	12,150	9,116	0.20	8,403	1.38

Table K-2. Runway Image Callout Range and Altitude - 35 GHz MMw Radar (Continued)

RUN TAG	RUN NUMBER	AIRPORT	PILOT	WX	RWY IMAGE CALLOUT ALTITUDE (FT)	DME RANGE TO XMITTER (NM)	DME XMITTER TO THRESHHOLD DISTANCE (FT)	DME RANGE TO THRESHHOLD (APPROX) (FT)	GLIDESLOPE ERROR AT RUNWAY IMAGE CALL DOTS	RANGE TO THRESHHOLD BASED ON ALTITUDE (FT)	RANGE TO THRESHHOLD BASED ON ALTITUDE (NM)
86	081892-2D	NTD	MN	NONE	No Call		12,150				
87	081892-2E	NTD	MN	NONE	470	3.70	12,150	10,331	0.00	8,981	1.48
88	081892-2F	NTD	MN	NONE	520	3.70	12,150	10,331	0.00	9,937	1.64
89	081892-2G	NTD	MN	NONE	480	3.60	12,150	9,724	0.00	9,172	1.51
90	081892-2H	NTD	MN	NONE	T/O		12,150				
91	081892-2I	NTD	MN	NONE	T/O		12,150				
92	081992-1A	SBA	MN	NONE	380	2.40	6,684	7,898	-0.30	7,524	1.24
93	081992-1B	SBA	MN	NONE	330	2.10	6,684	6,076	0.00	6,306	1.04
94	081992-1C	SBA	MN	NONE	310	2.10	6,684	6,076	-0.50	6,290	1.04
95	081992-1D	SBA	MN	NONE	250	1.90	6,684	4,860	0.00	4,777	0.79
96	081992-1E	VBG	MN	NONE	420	2.50	6,076	9,114	0.00	8,026	1.32
97	081992-1F	VBG	MN	NONE	480	2.70	6,076	10,329	0.00	9,172	1.51
98	081992-1G	VBG	MN	NONE	N/A		6,076				
99	082092-1A	SMX	MN	FOG	310	2.30	7,290	6,685	-0.10	5,994	0.99
100	082092-1B	SMX	MN	NONE	280	2.20	7,290	6,077	0.30	5,170	0.85
101	082092-1C	SMX	MN	NONE	290	2.20	7,290	6,077	0.10	5,478	0.90
102	082792-1A	VBG	CA	FOG	480	2.70	6,076	10,329	0.10	9,067	1.49
103	082792-1B	VBG	CA	FOG	480	2.70	6,076	10,329	0.00	9,172	1.51
104	082792-1C	VBG	CA	FOG	400	2.40	6,076	8,506	0.40	7,303	1.20
105	082792-1D	VBG	LO	FOG	260	2.00	6,076	6,076	0.00	4,968	0.82
106	082792-1E	VBG	LO	FOG	560	2.90	6,076	11,544	0.00	10,701	1.76
107	082792-1F	VBG	CA	FOG	540	2.90	6,076	11,544	0.00	10,319	1.70
108	082792-2A	ACV	LO	FOG	580	2.90	6,683	10,937	-0.10	11,214	1.85
109	082792-2B	ACV	LO	FOG	530	2.70	6,683	9,722	0	10,128	1.67
110	082792-2C	ACV	CA	FOG	460	2.60	6,683	9,115	-0.1	8,894	1.46
111	082792-2D	ACV	CA	FOG	550	2.70	6,683	9,722	0.40	10,042	1.65
112	082792-2E	ACV	CA	FOG	550	2.70	6,683	9,722	0.00	10,510	1.73
113	082892-1A	ACV	CA	FOG	290	1.80	6,683	4,254	0.60	5,179	0.85
114	082892-1B	ACV	CA	FOG	310	2.10	6,683	6,077	0.00	5,924	0.97
115	082892-1C	ACV	LO	FOG	260	1.90	6,683	4,861	-0.90	5,551	0.91
116	082892-1D	ACV	LO	FOG	450	2.50	6,683	8,507	0.00	8,599	1.42
117	082892-1E	ACV	LO	FOG	530	2.70	6,683	9,722	0.20	9,897	1.63
118	082892-1F	ACV	LO	FOG	540	2.90	6,683	10,937	0.00	10,319	1.70
119	082892-1G	ACV	CA	FOG	590	3.00	6,683	11,545	0.20	11,017	1.81
120	082892-1H	ACV	CA	FOG	460	2.60	6,683	9,115	-0.50	9,334	1.54
121	082892-2A	ACV	LO	FOG	280	1.80	6,683	4,254	0.50	5,056	0.83
122	082892-2B	ACV	LO	FOG	530	2.70	6,683	9,722	0.20	9,897	1.63
123	092392-1A	SMX	LO	FOG	275	2.50	7,290	7,900	0.00	5,255	0.86
124	092392-1B	SMX	LO	FOG	290	2.30	7,290	6,685	0.90	5,015	0.83
125	092392-1C	SMX	LO	FOG	225	2.10	7,290	5,470	0.00	4,299	0.71
126	092592-1A	LFI	MN	R-W	No call		6,076				
127	092592-1B	LFI	MN	R-W	345	1.80	6,076	4,861	2.00	5,347	0.88
128	092592-1C	NHK	MN	R-F	No image		7,291				
129	092592-1D	NHK	MN	R-F	240	1.90	7,291	4,253		4,586	0.75

Table K-2. Runway Image Callout Range and Altitude - 35 GHz MMw Radar (Continued)

RUN TAG	RUN NUMBER	AIRPORT	PILOT	WX	RWY IMAGE CALLOUT ALTITUDE (FT)	DME RANGE TO XMITTER (NM)	DME XMITTER TO THRESHHOLD DISTANCE (FT)	DME RANGE TO THRESHHOLD (APPROX) (FT)	GLIDESLOPE ERROR AT RUNWAY IMAGE CALL DOTS	RANGE TO THRESHHOLD BASED ON ALTITUDE (FT)	RANGE TO THRESHHOLD BASED ON ALTITUDE (NM)
130	092592-1E	MIV	MN	RF	148		N/A		0.20	2,764	0.45
131	092592-1F	MIV	MN	RF	NONE		N/A				
132	092592-1G	ACY	MN	R-F	NONE		3,038				
133	092592-1H	ACY	MN	RF	NONE		3,038				
134	092592-1I	ACY	MN	RF	241	1.70	3,038	7,291	-0.50	4,890	0.80
135	092692-1A	ORH	MN	R-F	290	No DME			0.20	5,415	0.89
136	092692-1B	ORH	MN	R-F	370	No DME			0.00	7,070	1.16
137	092692-1C	ORH	MN	R-F	370	No DME			0.20	6,909	1.14
138	092692-1D	ORH	MN	R-F	NONE	No DME					
139	092692-1E	ORH	MN	R-F	370	No DME			0.00	7,070	1.16
140	092692-2A	ORH	MN	R-F	370	No DME			0.00	7,070	1.16
141	092692-2B	ORH	MN	R-F	420	No DME			0.10	7,933	1.31
142	092692-2C	ORH	MN	R-F	400	No DME			0.00	7,643	1.26
143A	092792-1A	ACY	MN		400	1.90	3,038	8,506	1.90	6,258	1.03
143B	092792-1B	MIV	MN		400				-0.20	7,826	1.29
143C	092792-1C	NHK	MN		500	2.60	7,291	8,507	0.20	9,337	1.54
144	092892-1A	HTS	MN	F	370	No DME			0.00	7,070	1.16
145	092892-1B	HTS	MN	F	370	No DME			0.20	6,909	1.14
146	092892-1C	HTS	MN	F	270	No DME			-0.50	5,479	0.90
147	092892-1D	HTS	MN	F	320	No DME			-0.30	6,336	1.04
148	092892-1E	HTS	MN	F	320	No DME			-0.30	6,336	1.04
149	092892-1F	HTS	MN	F	420	No DME			0.10	7,933	1.31
SUTABILITY RUNS FOR LEAR 94 GHZ RADAR											
150	102692-1A	NTD	CA		170	2.40	12,150	2,432	-0.80	3,583	0.59
151	102692-1B	NTD	CA		150	2.60	12,150	3,648	-0.70	3,121	0.51
152	102692-1C	NTD	CA		150	2.40	12,150	2,432	-0.50	3,044	0.50
153	102692-1D	NTD	RH		160	2.40	12,150	2,432	0.50	2,889	0.48
154	102692-1E	NTD	RH		130	2.40	12,150	2,432	0.10	2,456	0.40
155	102692-1F	VNY	RH		190	0.40	-2,430	4,860	-1.20	3,130	0.52
156	102892-1A	SBA	RH		200	1.40	6,684	1,822	0.60	3,572	0.59
157	102892-1B	SMX	RH		170	2.00	7,290	4,862	0.00	3,248	0.53
158	102892-1C	SMX	RH		140	1.60	7,290	2,432	0.00	2,675	0.44
159	102892-1D	VBG	RH		170	INOP	6,076		2.00	2,635	0.43
160	102892-1E	VNY	RH		220	0.20	-2,430	3,645	0.00	3,235	0.53

Table K-2. Runway Image Callout Range and Altitude - 35 GHz MMw Radar (Continued)

RUN TAG	RUN NUMBER	AIRPORT	PILOT	WX	RWY IMAGE CALLOUT ALTITUDE (FT)	DME RANGE TO XMITTER (NM)	DME XMITTER TO THRESHHOLD DISTANCE (FT)	DME RANGE TO THRESHHOLD (APPROX) (FT)	GLIDESLOPE ERROR AT RUNWAY IMAGE CALL DOTS	RANGE TO THRESHHOLD BASED ON ALTITUDE (FT)	RANGE TO THRESHHOLD BASED ON ALTITUDE (NM)
161	112092-1A	NTD	CA	VFR	470	3.70	12,150	10,331	-0.20	9,195	1.51
162	112092-1B	PUB	CA	SNOW	No Image						
163	112092-1C	PUB	CA	SNOW	No Image						
164	112092-1D	PUB	MN	SNOW	No Image						
165	112092-1E	PUB	MN	SNOW	No Image						
166	112192-1A	PUB	MN	Plowed Rwy	130	4.30	23,069	3,058	-0.20	2,543	0.42
167	112192-1B	PUB	MN	Plowed Rwy	70	3.90	23,069	627	-0.20	1,370	0.23
168	112192-1C	COS	CA	Plowed Rwy	150	NO DME			-0.50	3,044	0.50
169	112192-1D	COS	CA	Plowed Rwy	No Image	NO DME					
170	112792-1A	NTD	MN	VFR	760	3.40	12,150	8,508	Non Precision		1.40
171	112792-1B	NTD	MN	VFR	700	3.70	12,150	10,331	Non Precision		1.70
172	112792-1C	NTD	MN	VFR	570	3.30	12,150	7,901	Non Precision		1.30
173	112792-1D	NTD	CA	VFR	480	3.70	12,150	10,331	Non Precision		1.70
174	112792-1E	NTD	CA	VFR	540	3.70	12,150	10,331	Non Precision		1.70
175	112792-1F	NTD	CA	VFR	650	3.70	12,150	10,331	Non Precision		1.70
176	112792-1G	VNY	CA	VFR	450	NO DME				8,599	1.42

APPENDIX L

PLOTS OF CLEAR WEATHER CONTRAST

FOR

REGIONS OF INTEREST (ROI)

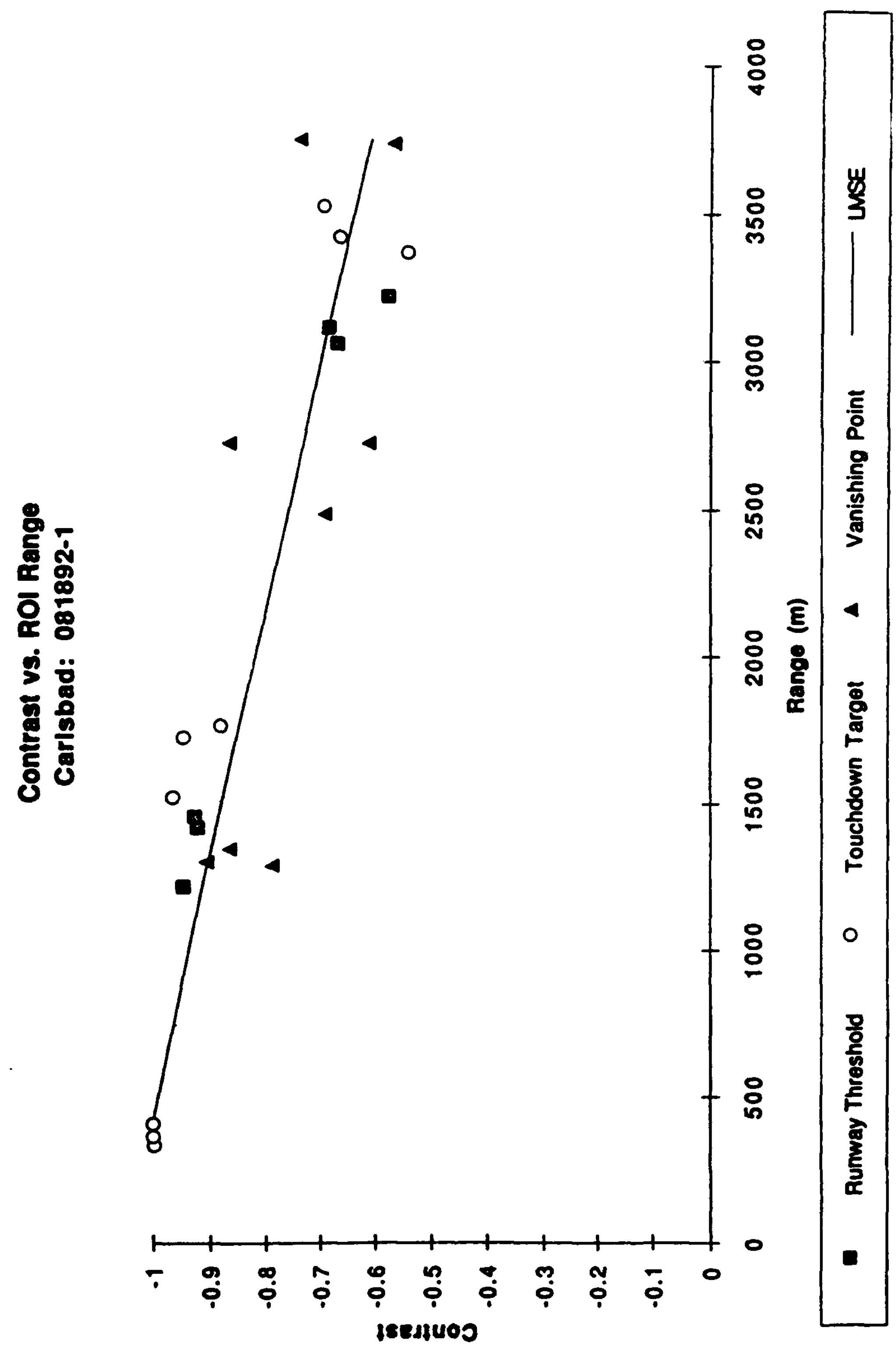

Figure L-1. Plot of Contrast Versus Range to Region of Interest for Clear Weather at Carlsbad on August 18, 1992 (Approaches 1G-11)

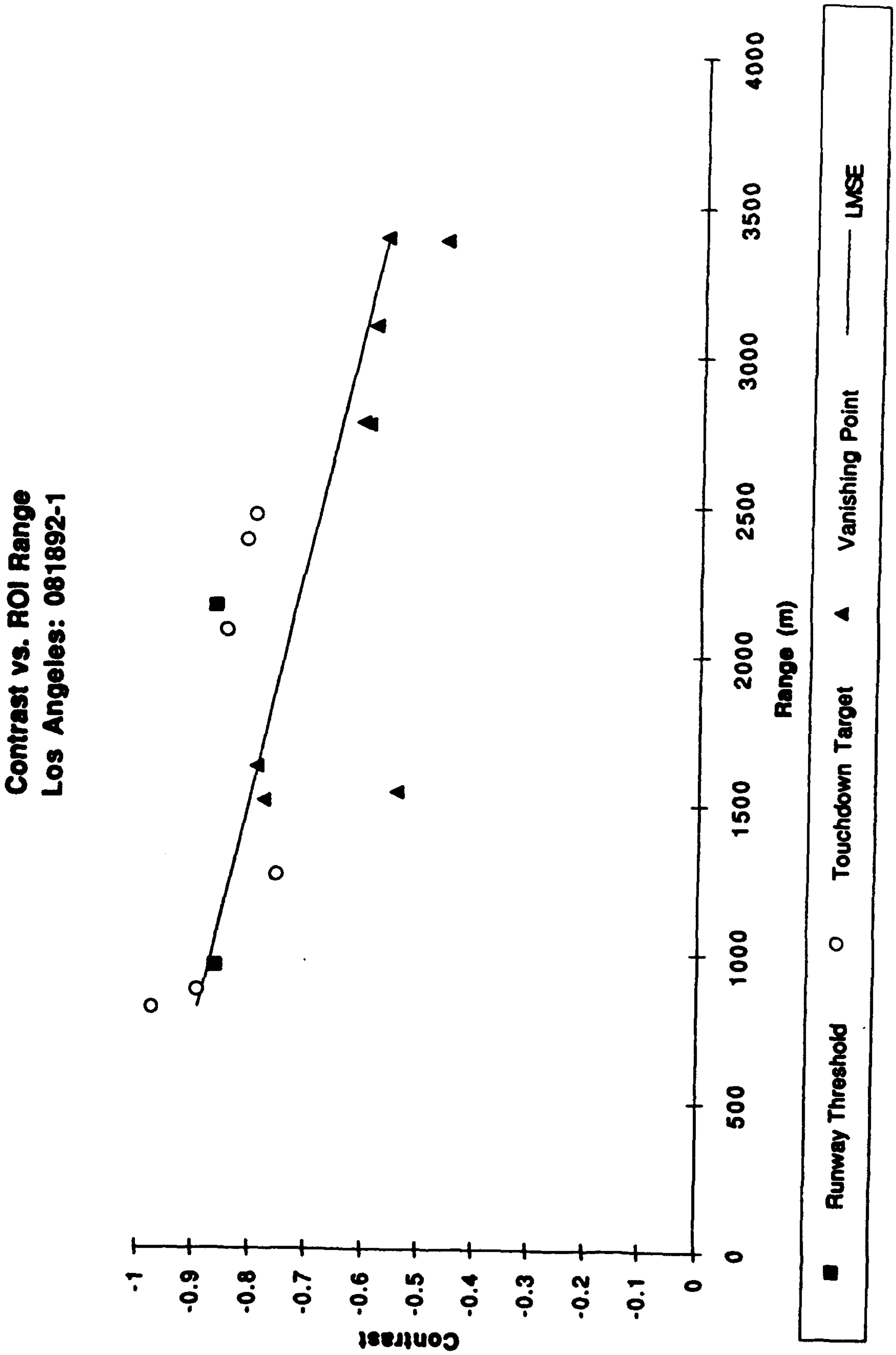

Figure L-2. Plot of Contrast Versus Range to Region of Interest for Clear Weather at Los Angeles on August 18, 1992 (Approaches 1A1C)

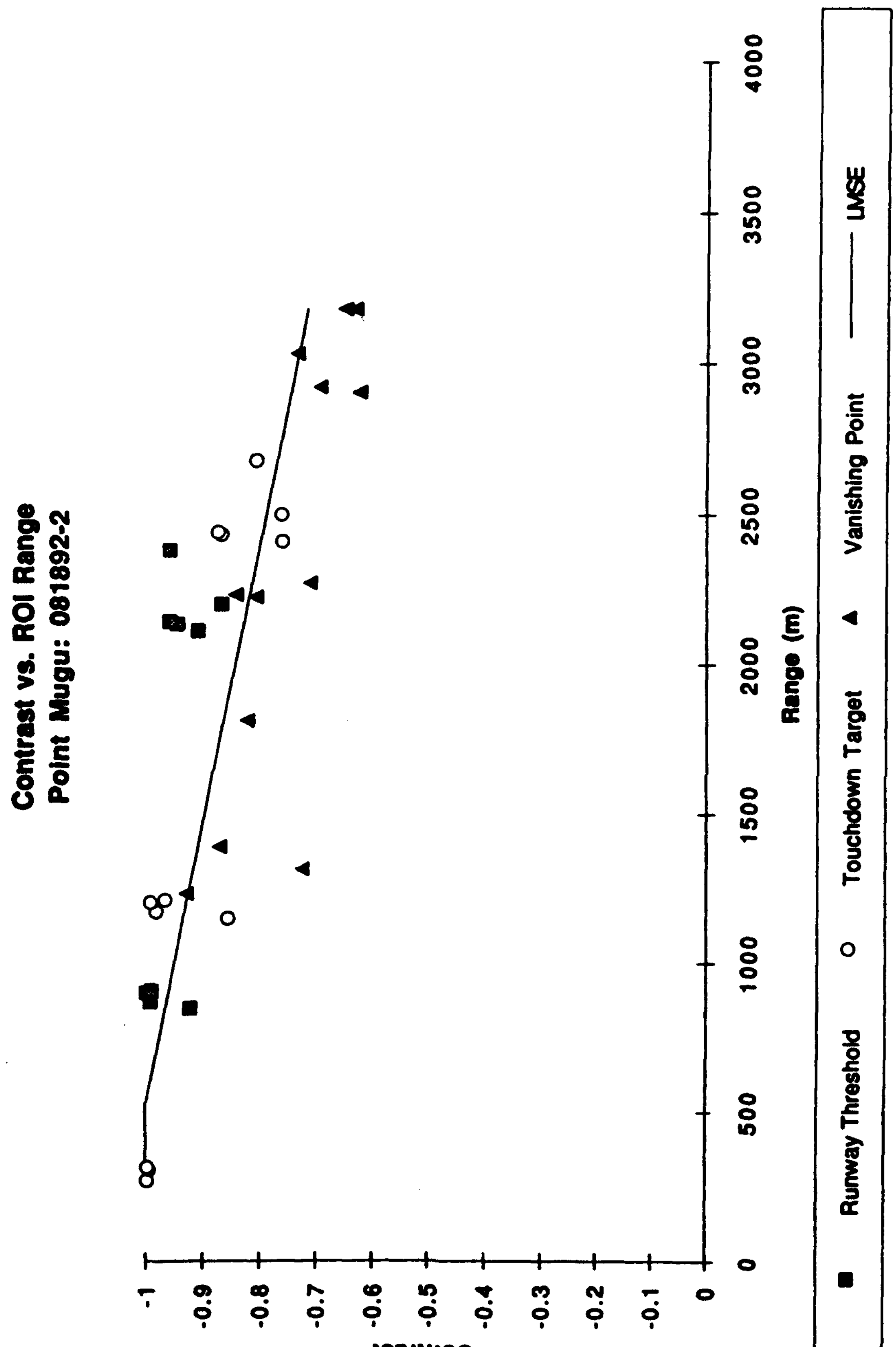

Figure L-3 Plot of Contrast Versus Range to Region of Interest for Clear Weather at Point Mugu on August 18, 1992 (Approaches 2A-2G)

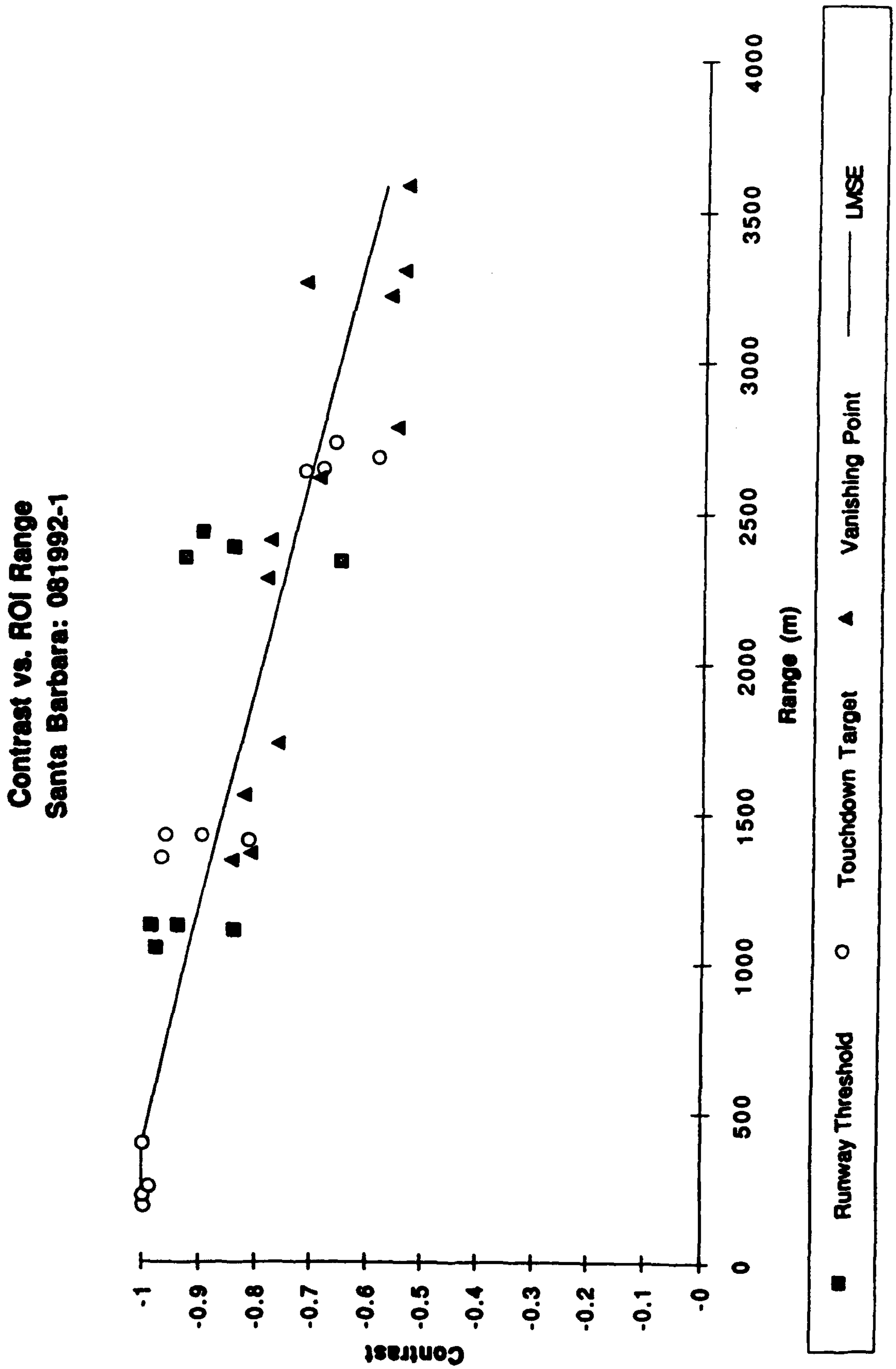

Figure L-4. Plot of Contrast Versus Range to Region of Interest for Clear Weather at Santa Barbara on August 19, 1992 (Approaches 1A1D)

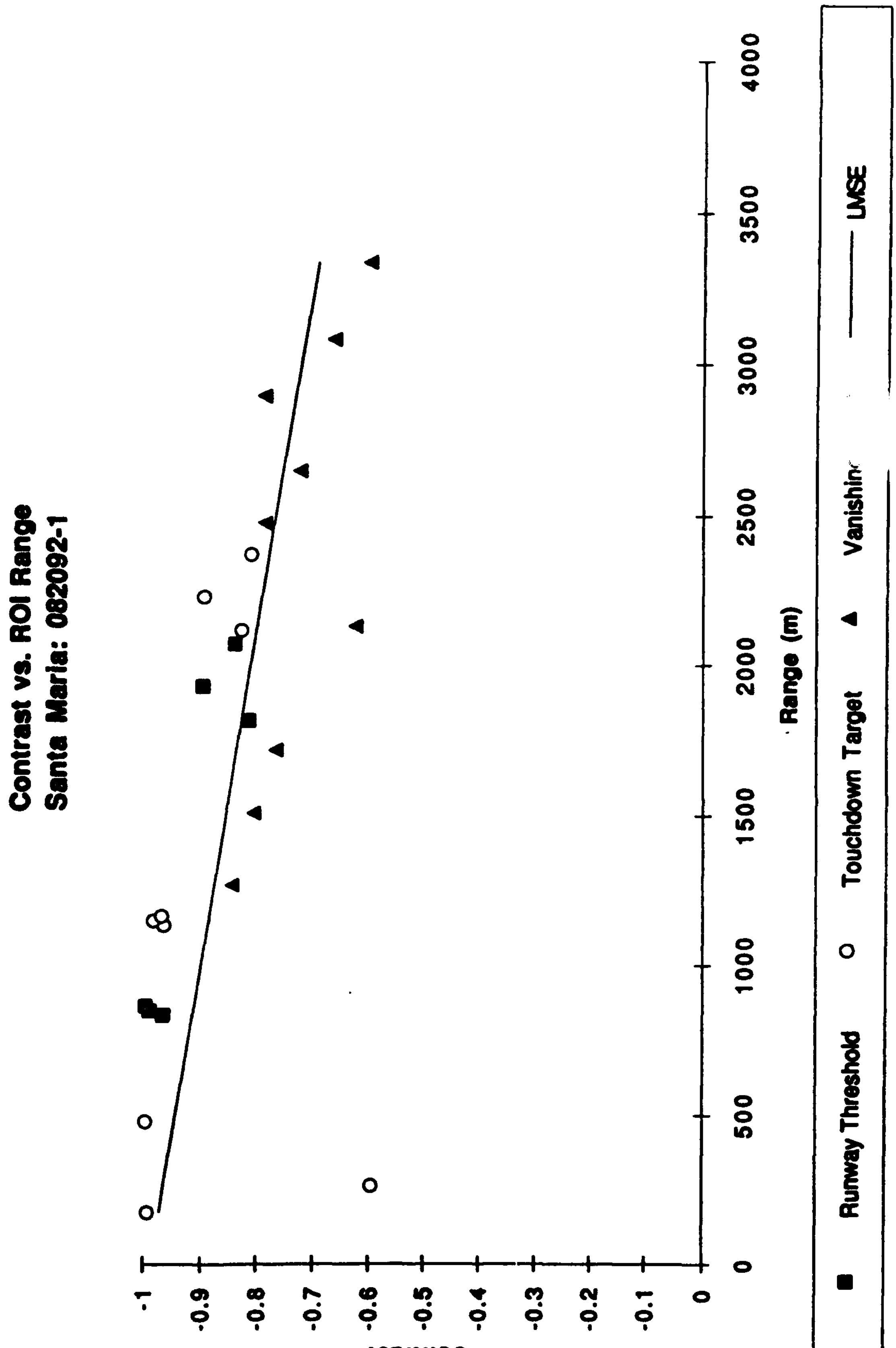

Figure L-5. Plot of Contrast Versus Range to Region of Interest for Clear Weather at Santa Maria on August 20, 1992 (Approaches 1A1C)

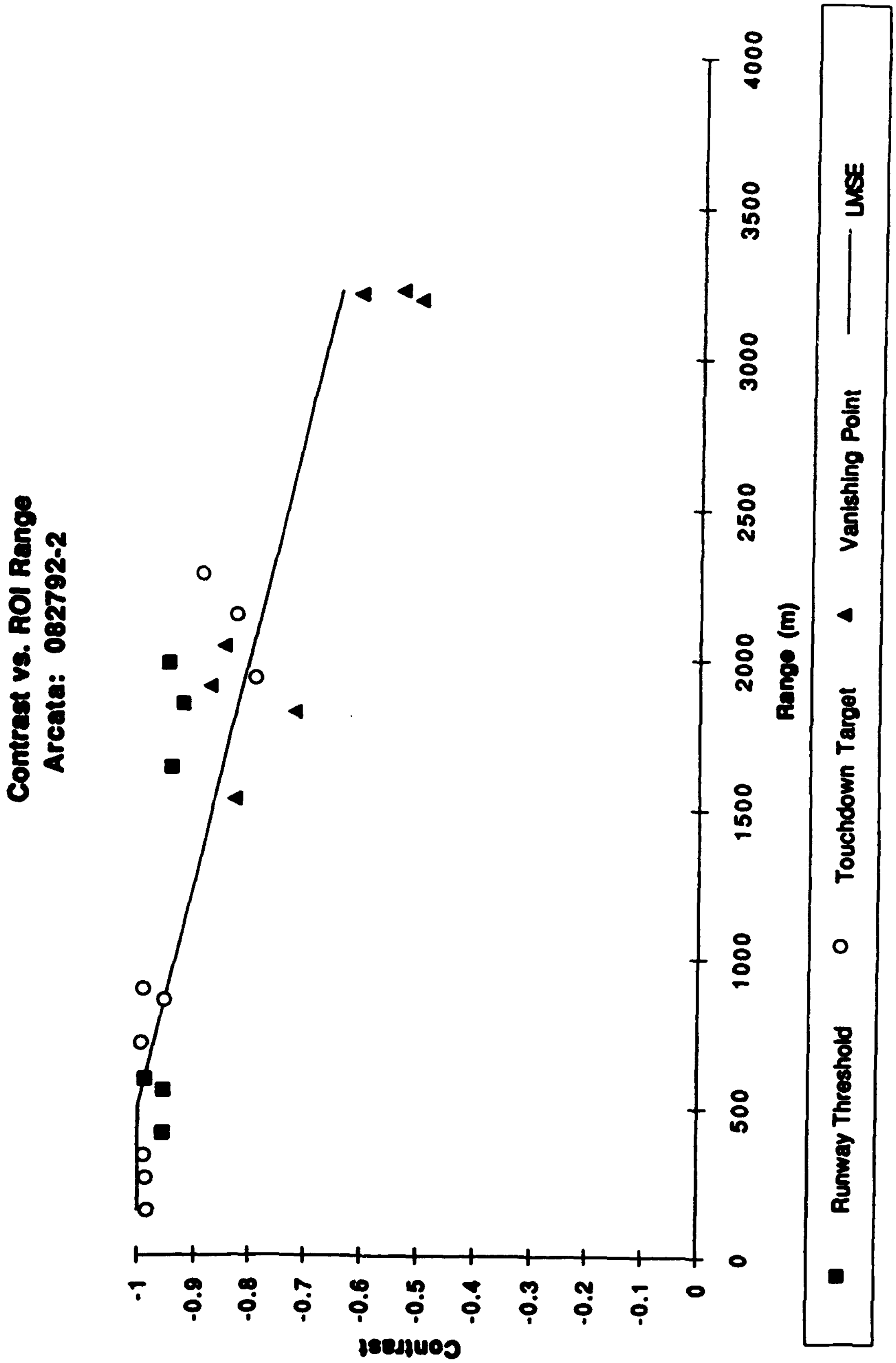

Figure L-6. Plot of Contrast Versus Range to Region of Interest for Clear Weather at Arcata on August 27, 1992 (Approaches 2A2C)

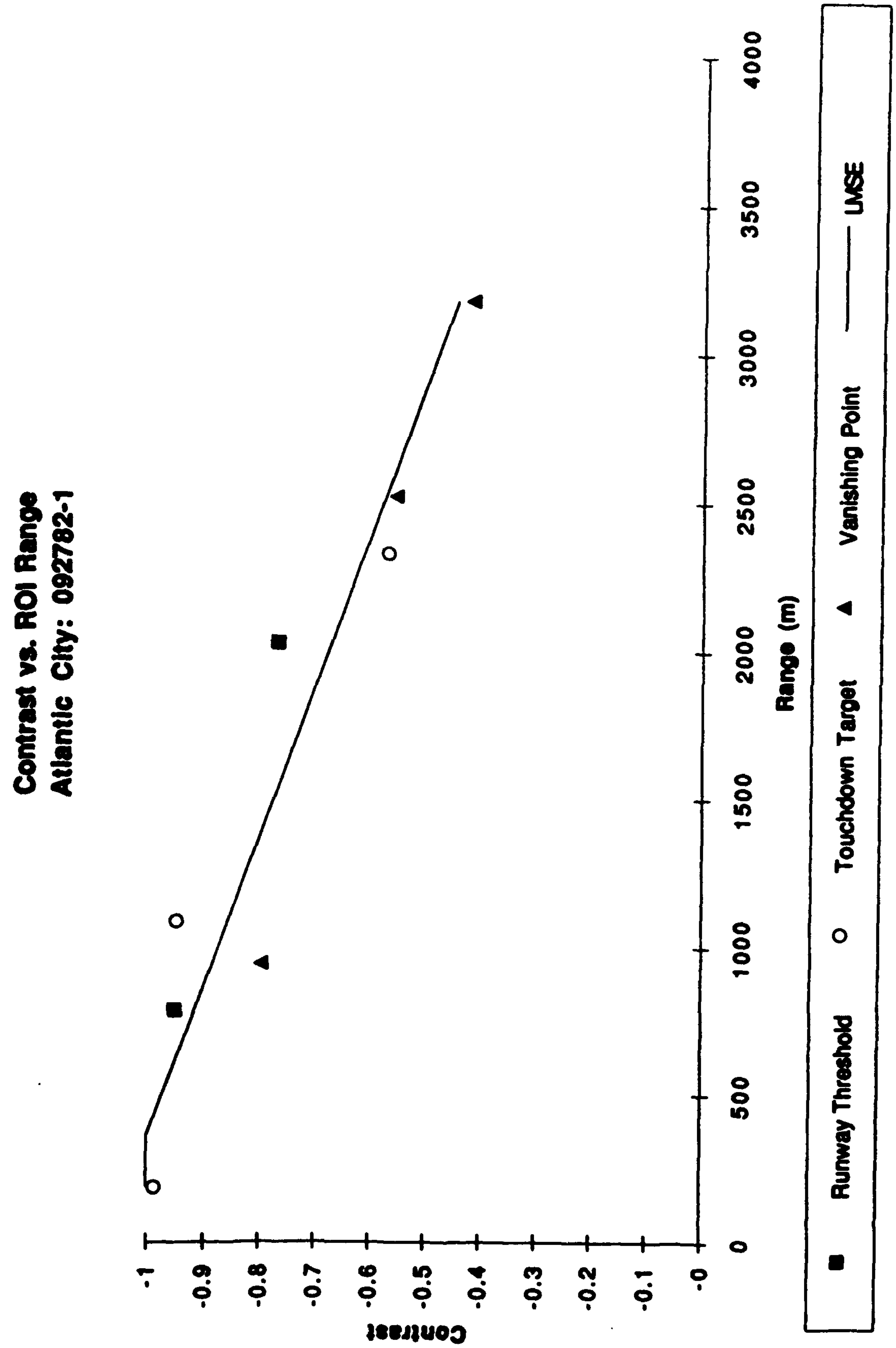

Figure L-7. Plot of Contrast Versus Range to Region of Interest for Clear Weather at Atlantic City on September 27, 1992 (Approaches 1A)

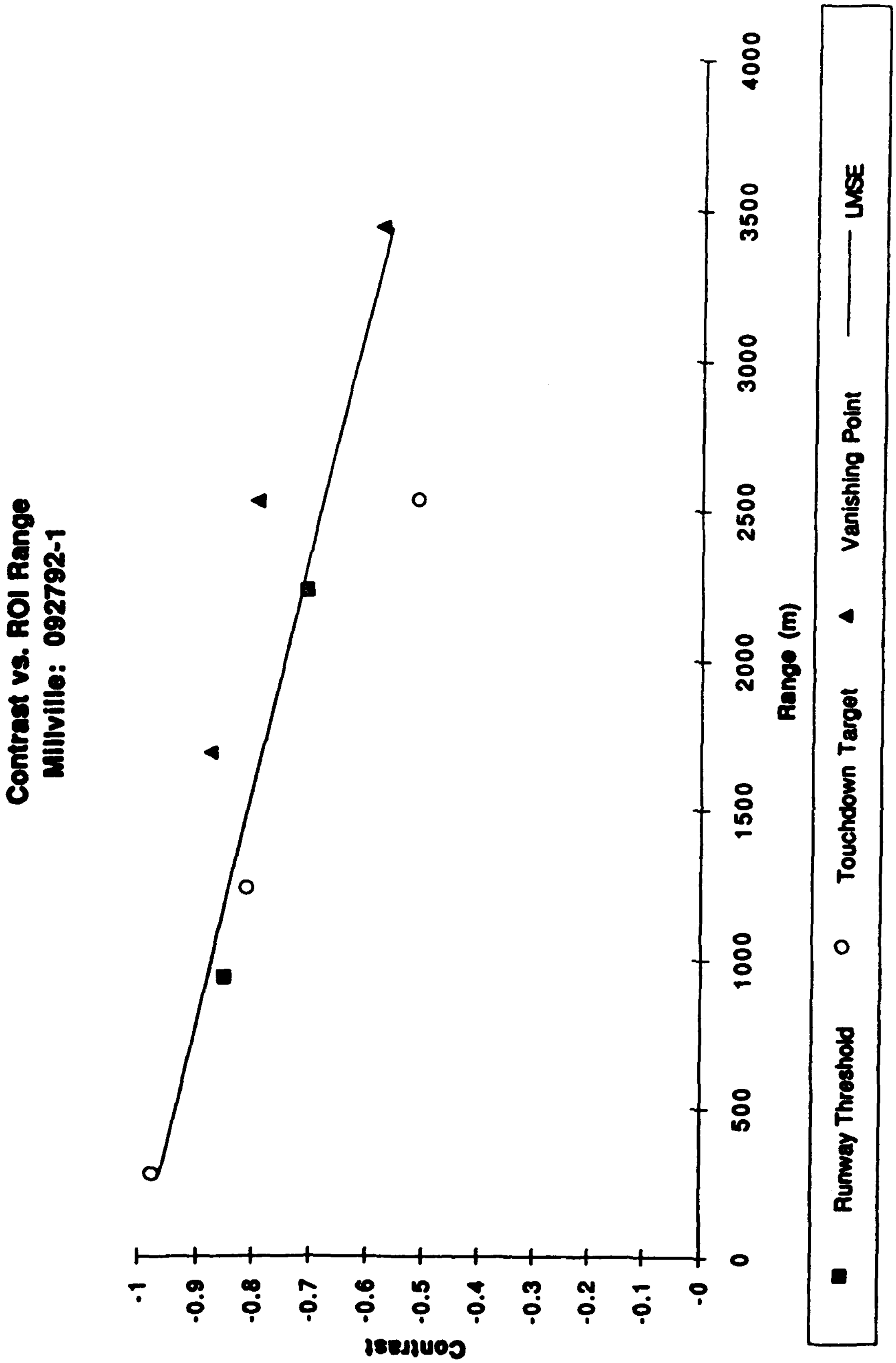

Figure L-8. Plot of Contrast Versus Range to Region of Interest for Clear Weather at Carlsbad on September 27, 1992 (Approaches 1B)

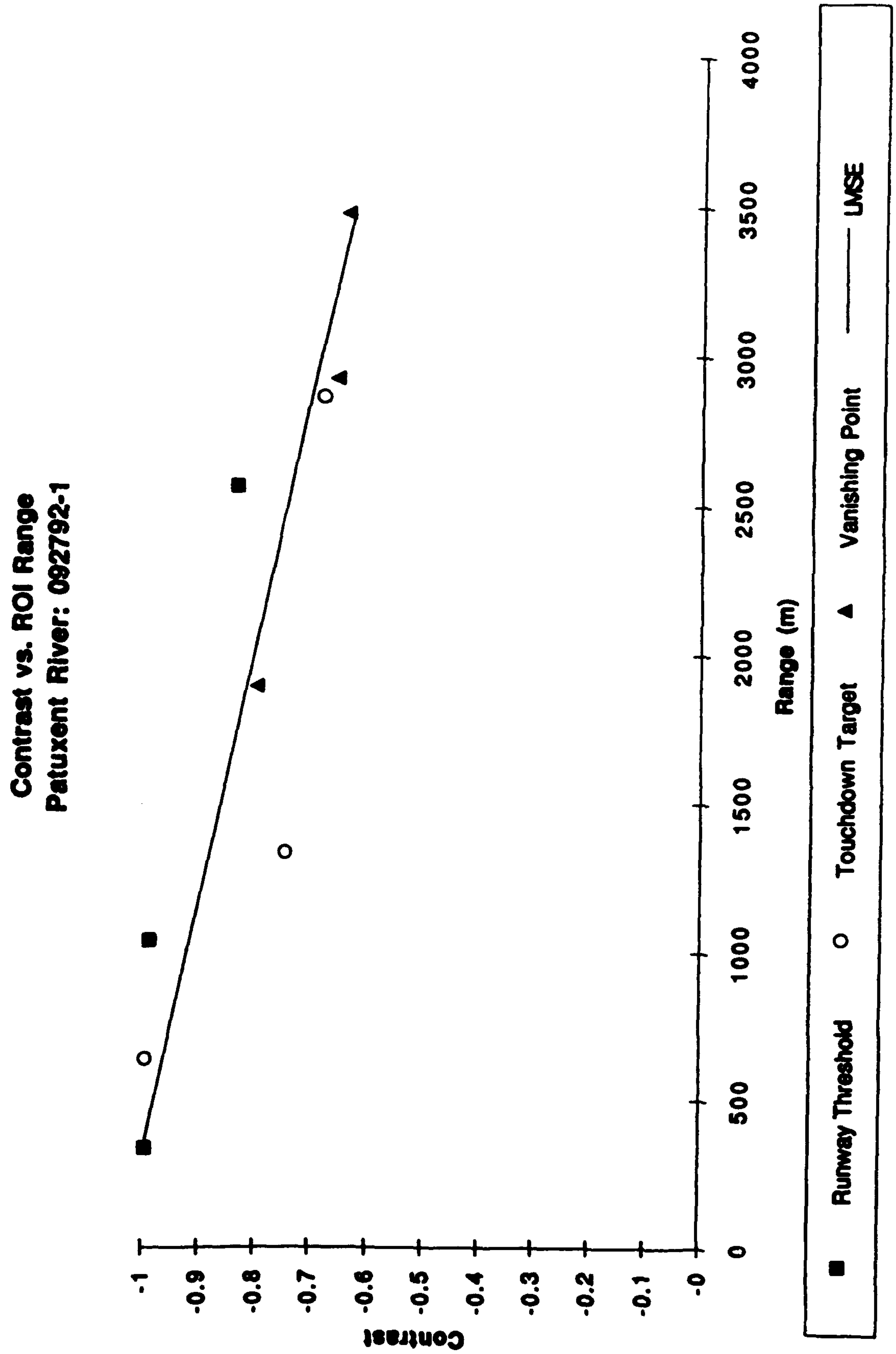

Figure L-9. Plot of Contrast Versus Range to Region of Interest for Clear Weather at Patuxent River on September 27, 1992 (Approaches 1C)

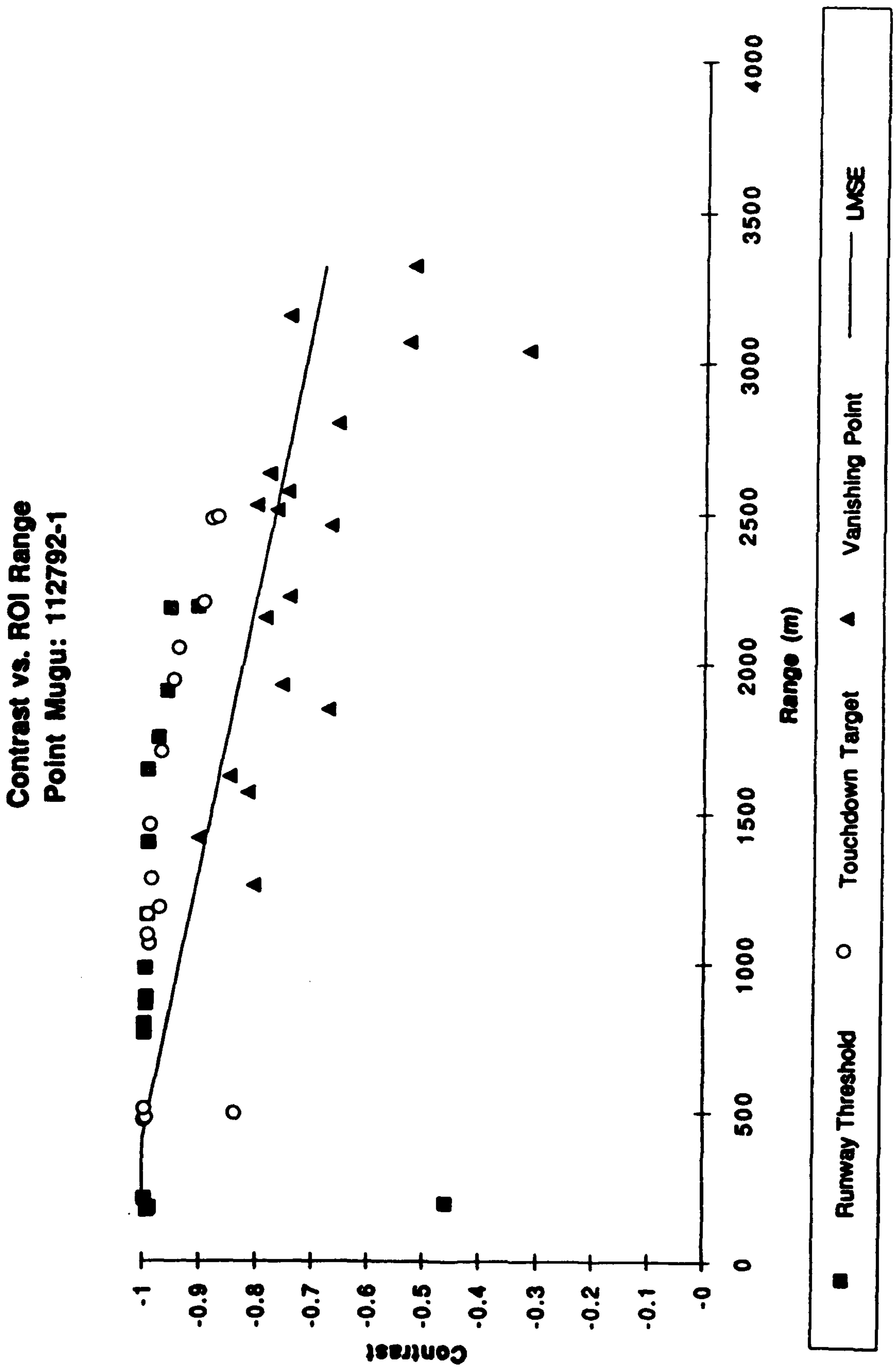

Figure L-10. Plot of Contrast Versus Range to Region of Interest for Clear Weather at Point Mugu on November 27, 1992 (Approaches 1A-1F)

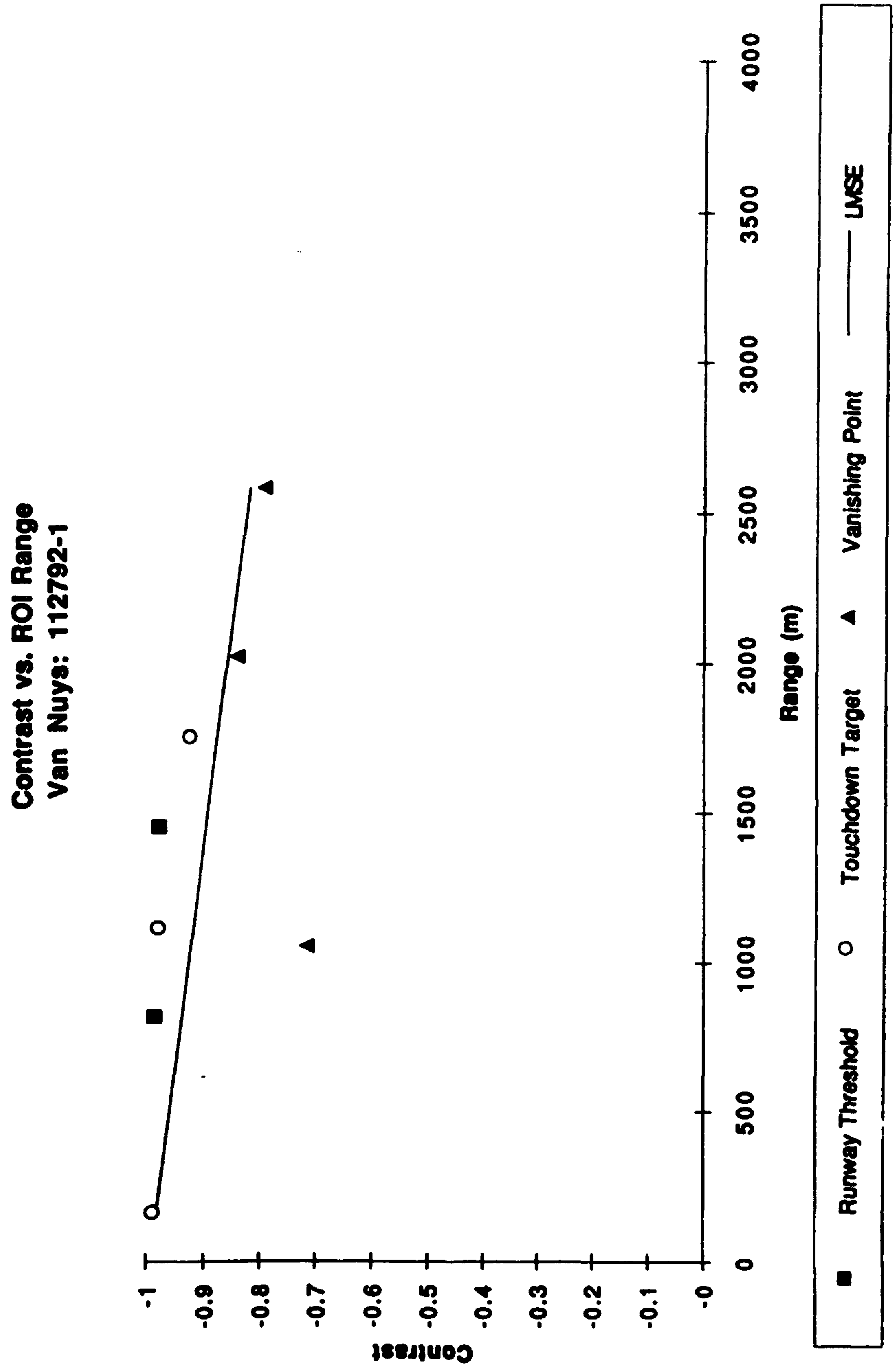

Figure L-11 Plot of Contrast Versus Range to Region of Interest for Clear Weather at Van Nuys on November 27, 1992 (Approaches 1G)

APPENDIX M

SYNTHETIC VISION TECHNOLOGY DEMONSTRATION
35 GHz RADOME TEST

TEST RATIONALE AND METHODOLOGY

Subcontractor Norton Company manufactured a special radome for the SVSTD Gulfstream II test aircraft with optimum performance at the 35 GHz operating frequency of the Honeywell candidate radar sensor. Mounted below the existing X-band weather radar in the aircraft nose, the SVSTD radar sensor antenna radiates through the lower hemisphere of the radome. K_a-band linear polarization transmission efficiency measurements performed by Norton on a flat-panel sample correlated well with modeled efficiency curves at angles off perpendicular of 0°, 30°, and 45°. The radome material is designed for minimum variations in transmission efficiency at 35.3 GHz over angles of 0° to 60° from the perpendicular. However, the completed radome structure had not been tested with the candidate radar system. The radome operational differences introduced in the SVSTD flight test configuration compared to the lab test configuration were 1) completed radome vs. flat-panel sample, 2) circular polarization vs. linear, 3) wide-aperture Honeywell antenna vs. standard gain horn, and 4) far-field vs. near-field measurements.

At the request of the FAA and TRW, GTRI performed a ground test of the Norton radome on the test aircraft at the Midcoast Aviation facility in St. Louis to verify the radome transmission efficiency. The Honeywell radar sensor, operating in the tower test mode, along with a radar reflector, served as the test instruments to perform this evaluation. With the radar antenna in "stare" mode, the radar reflector was placed in the beam at a far-field distance, and the reflector's received signal level was measured on an oscilloscope. Special considerations were made to reduce the effects of ground-bounce multipath on the reflector measurements.

The measurements were made first with the radome in place, and then repeated with the radome removed. The received power levels were compared to determine two-way transmission loss through the radome, using received power transfer curves developed during the tower tests. Since the installed antenna has a normal look-down angle of 2.5° or more, the antenna was tilted up to place the main beam on the reflector target. Tilting was accomplished by adjusting the antenna elevation mechanical tilt. The alternative tilting method of jacking the aircraft from the nose wheel was determined to not be practical. Calculation of the absolute received power or RCS was not required, since the measurement is based on a difference in received power levels.

TEST CONDUCTION

The radome measurements were performed on 26-27 May 1992 at the Midcoast Aircraft facility, St. Louis Downtown Parks Airport, Cahokia, Illinois. GTRI provided a radar reflector to serve as the test target, and a Polaroid oscilloscope camera to record the oscilloscope display. Midcoast Aircraft provided a portable oscilloscope, a stand for the radar reflector, assistance for reflector placement, and aircraft positioning. Radome removal and installation, plus radar antenna adjustments, were also performed by Midcoast Aircraft. Honeywell personnel operated the radar sensor system and controlled the radar antenna modes. Raleigh Jet and TRW personnel operated the aircraft auxiliary power unit and flight test electronics systems during the ground radome testing.

The Gulfstream II test aircraft was positioned at the edge of the paved ramp area overlooking the two parallel runways and surrounding grass areas. The radar antenna was tilted to place the elevation beam on the horizon. The 18.5 dBsm segmented-cylindrical-corner (SCC) radar reflector was installed on a short wooden ladder, and located in the grass adjacent to a taxiway at a range of 1065 m (3483 ft.), as shown in Figure M-1. A sighting aid was used to point the reflector directly towards the aircraft. The Honeywell radar antenna scanner was placed in the "stare" mode with an azimuth look angle of approximately 5° left of aircraft center-line. The narrow antenna azimuth beam was "steered" onto the target by moving the aircraft nose wheel sideward with a tow vehicle to maximize the reflector's radar return.

Figure M-2 is a block diagram of the measurement equipment setup. Radar receiver logarithmic video from the front panel test port was monitored on oscilloscope channel 1 with 50-ohm termination, and external triggering was from the PRF pulse. The reflector's received power level was measured by the return pulse amplitude, and the range was determined by the 7.1 μs return pulse delay from the transmit pulse. Oscilloscope photographs were made with no delay at settings of 0.2 V and 1 μs/div. (Figures M-3a & M-3c) and with delayed sweep at 0.1 V and 100 ns/div. (Figures M-3b & M-3d) for detailing the return pulse.

The reflector return level was measured on 26 May 1992 with the radome installed. The radome was removed the morning of 27 May 1992, and the measurement repeated. The aircraft was repositioned left and right to verify the antenna beam was centered on the reflector. Digital data "frames" were recorded with the Honeywell data acquisition system (DAS) as backup to the oscilloscope data. The radome was replaced early afternoon on 27 May 1992, and the reflector

return signal was measured for a third time. After testing, the reflector was removed from its location.

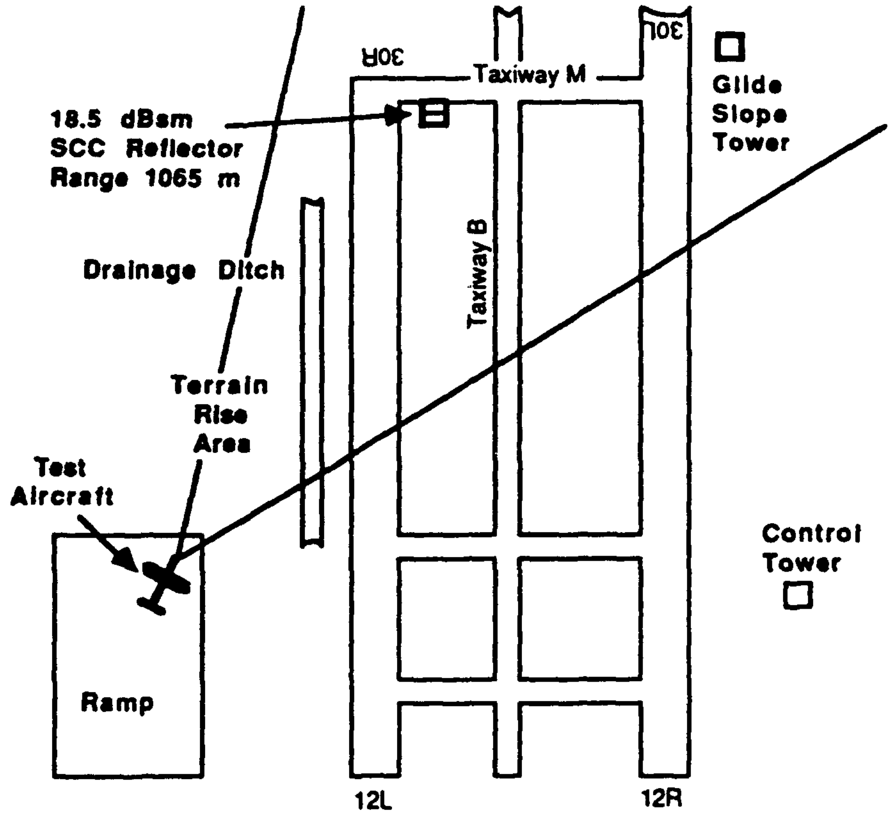

Figure M-1. Test Scene at St. Louis Parks Airport

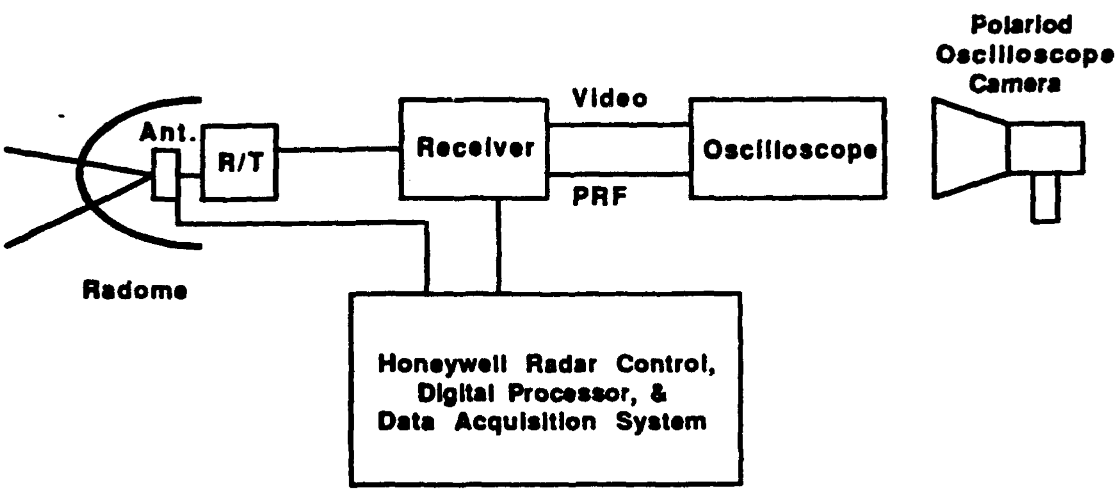

Figure M-2. Measurement Equipment Setup Diagram

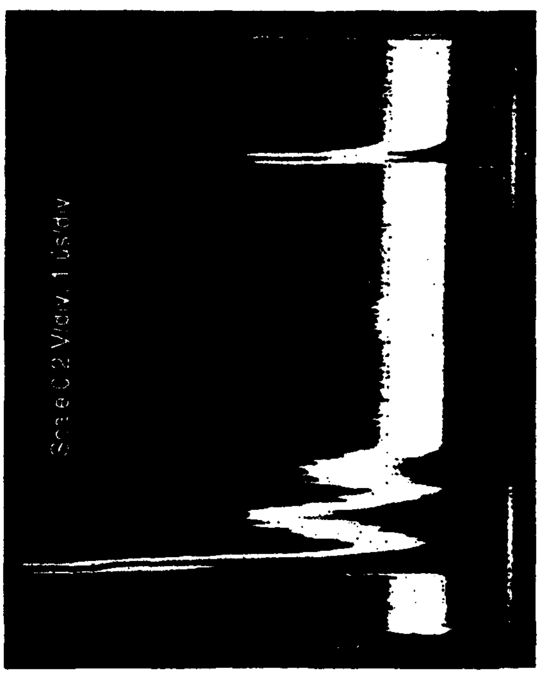

Figure 3a. Range display with radome.

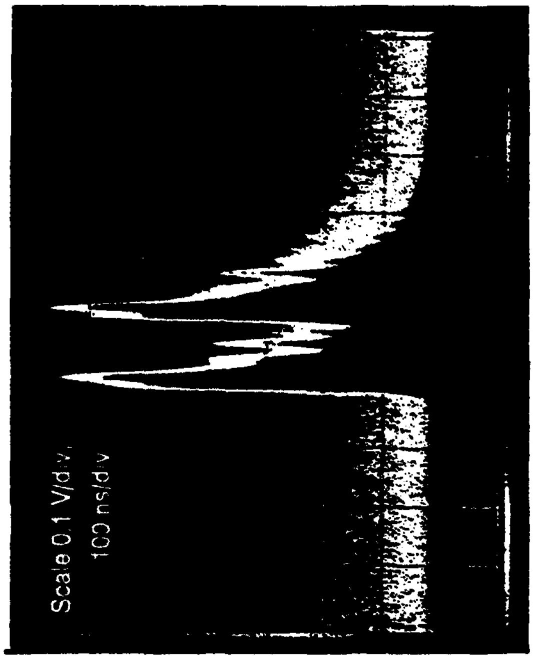

Figure 3b. Reflector detail with radome.

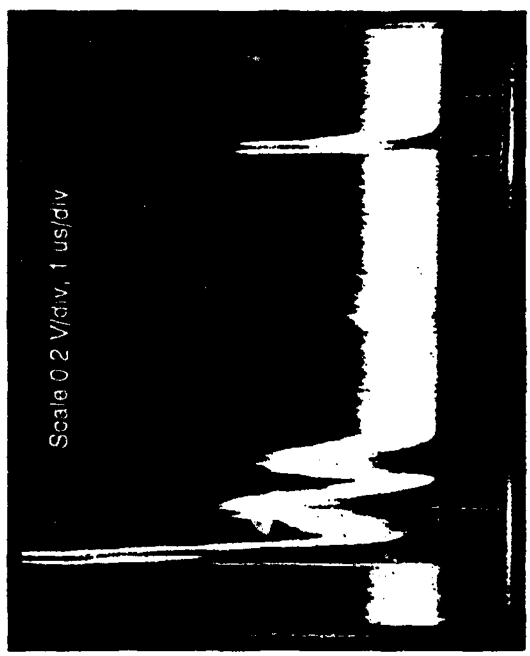

Figure 3c. Range display without radome.

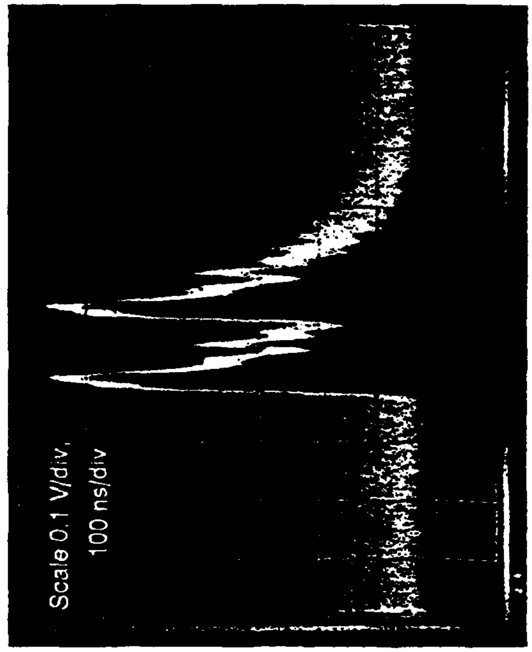

Figure 3d. Reflector detail without radome.

Figure 3. Oscilloscope Photographs of Range Display

Figure M-3. Oscilloscope Photographs of Range Display

ANALYSIS AND RESULTS

The measured two-way attenuation through the radome was 1 dB, with an estimated measurement error of -1 dB to +2 dB. The following paragraphs cover the analysis methods used and possible sources of measurement error. The radome attenuation measurements were made under time and budget constraints, and with the available test support equipment. Test methods were chosen to make the most accurate RF measurements within these constraints. These measurements would have detected a large two-way attenuation value of 4 dB or more, but lack the necessary precision to resolve among low values of attenuation.

The Honeywell radar receiver uses a 160 MHz second intermediate frequency (IF) amplifier with logarithmic detector circuit. The video output voltage is proportional to the log of the received power over a 60 dB dynamic range. Video output saturation occurs between 1.5 V and 2.0 V, depending on the termination resistance. During the tower tests, the receiver RF-to-video transfer function was characterized using a CW signal injection method. The receiver transfer curve data are shown in Figure M-4. Saturation for the first four attenuator settings was due to A/D converter clipping, and not the log video saturating. A/D full-scale voltage (255 counts) was 1.0 V. The gain sensitivity between the 40 dB and 20 dB attenuator settings (equivalent to -75 dBm and -55 dBm received power) was 249 minus 130 counts divided by 20 dB, or 6 counts/dB. If 255 counts is 1 V (full-scale), then 6 counts equals 24 mV. The reflector return pulse peak amplitude value was 660 mV with the radome installed, and 680 mV with the radome removed. The 20 mV video signal difference was equal to a received power difference of 1 dB.

A review of the possible measurement error sources finds antenna pointing errors and radar amplitude instability to be the major contributors. The Honeywell radar "stare" mode directs the antenna beam to approximately -5° azimuth. The stare mode was implemented in the design only for diagnostics and tower testing, so fine azimuth positioning was not included. Moving the reflector became the preferred method for centering the reflector in the antenna beam, but this option was not available. Reliable radio communication could not be established from the reflector location to the aircraft. The option of moving the aircraft precisely to direct the beam would have introduced measurement error, since the two-way 3 dB antenna azimuth beamwidth is only 0.5°. The oscillo-scope photographs reveal a radar problem that caused the return pulse from a single target, such as the reflector, to be split into two small pulses. Instead of being measured from a

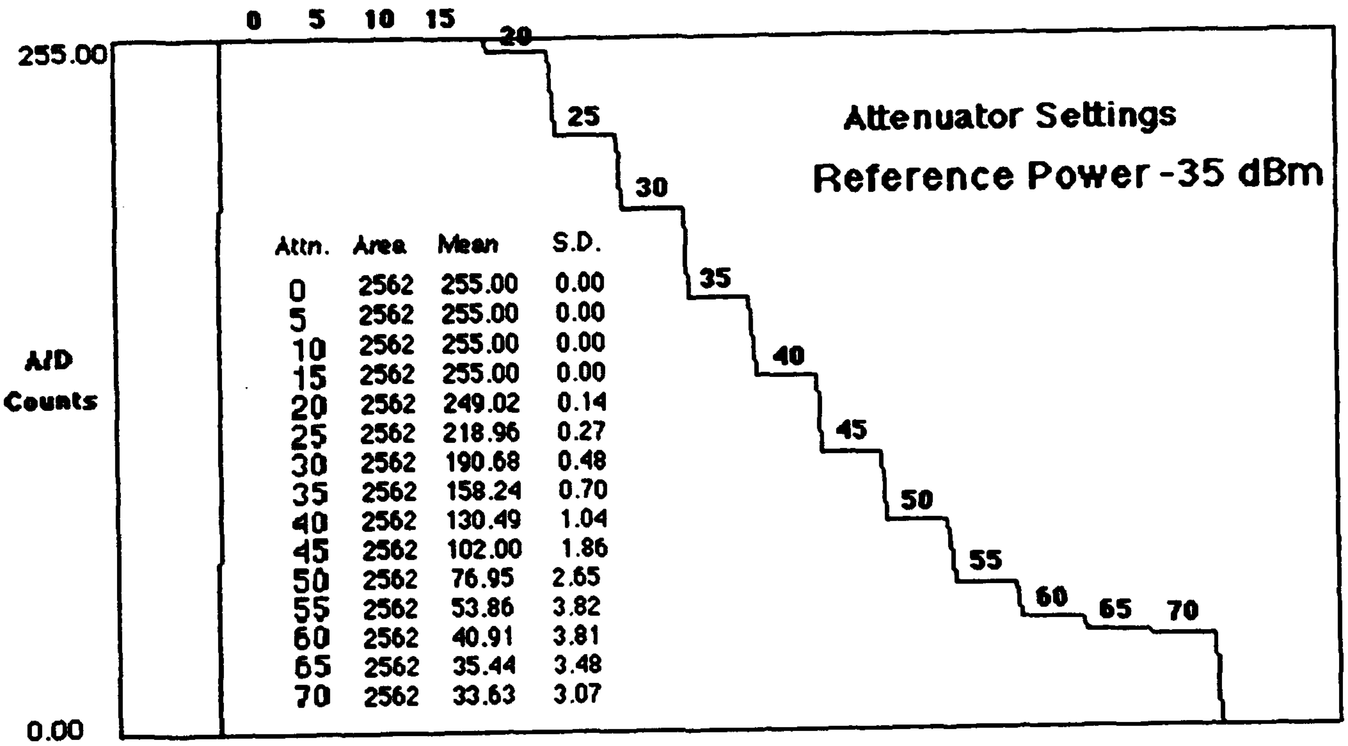

Figure 4. Radar Receiver Transfer Curve

single wide pulse, the amplitude values were made from two smaller, less stable, return pulses. The radar problem was subsequently diagnosed, and was repaired prior to flight testing.

Other possible measurement error sources include multipath to the reflector, antenna elevation pointing, manual tuning of the radar local oscillator, and radar receiver calibration. The measurement area included a small rise in the terrain covered with deep grass between the radar and the reflector, that minimized any multipath ground bounce. When the installed reflector was rocked over a wide arc, no significant return amplitude fluctuation was detected, thus indicating multipath effects were minimal. The 1065 m target range is definitely in the far-field of either the antenna or the reflector. For the reflector measurements, the radar antenna tilt was elevated by 3° from the normal 6° position to the indicated 9° position. The normal 2.5° look-down angle was, therefor, changed to a 0.5° look-up angle. This adjustment was sufficient to properly place the relatively-wide elevation beam on the reflector. The elevation change does mean that the radar was operating more through the "nose" of the radome, rather than through the lower hemisphere, but the 3° difference in tilt should have a small effect.

Manual tuning of the radar local oscillator was necessary during these measurements. The repeatability of manual tuning is considered very good, using the built-in tuning indicator. A new receiver/transmitter (R/T) unit was constructed by Honeywell for the flight tests. The receiver transfer curve in Figure 4 was made using the previous Honeywell R/T unit. The radar's second IF section, including logarithmic detector and amplifier, are common to both system configurations. Tower test measurements were made the same day with both configurations, so calibration traceability is maintained. Although there may be a difference in the absolute sensitivity with the two R/T units, the delta received power calibration values are unchanged. Radar receiver calibration differences will, therefore, not affect the accuracy of the radome attenuation measurements.